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U.K.–U.S.A. Exchange

THE recent agreement between the U.S.A. and the U.K. on the exchange of nuclear information of a military character, has caused widespread concern that industrial know-how of real commercial significance has been bartered for a naval propulsion unit. This misapprehension arises in part from the tendency to associate the term Calder Hall not only with the actual station but also with the civilian power reactors and from a confusion with the agreement negotiated in September, 1956, which provided for a complete and free exchange of patents and inventions held by the two Governments on November 15, 1955.

The two agreements are, however, essentially different in character. The more recent arrangement in effect covers—in the words of the White Paper—the exchange of information necessary for the improvement of atomic weapons design, development and fabrication capability. Calder Hall is a plutonium production reactor and must, therefore, come directly within the scope of a comprehensive military exchange in the same way that the Nautilus propulsion unit is essentially a military installation. It is probable that the Calder Hall reactor bears a closer relation to developed civilian power stations in the U.K. than does the Nautilus unit to future stations in the U.S.A., but this does not mean that the release of hitherto unpublished information on Calder will materially affect American civilian power developments. It is understood that the outstanding information not given on Calder concerned the fuel elements, more particularly the detailed treatment of the uranium to minimize distortion and certain details concerning the actual fabrication of the elements.

Commercial Significance

It must be appreciated, however, that the information to be released is only that owned by the Atomic Energy Authority and the developments initiated by industry are not involved. Furthermore, although America is likely to begin soon the construction of a prototype gas-cooled civilian power reactor, there is practically no possibility of uranium metal being used as fuel nor of Magnox being employed as canning material. The only reactor system which might possibly benefit from an increased knowledge of uranium treatment is the organic moderated. With regard to heat transfer surfaces, the Calder element shape has been fully published and the finning configurations that have been developed by the groups remain the property of the groups and will not be disclosed. In reality, as more reactors of British design are built abroad there is little doubt that these designs will become general property, but again it is unlikely that any American systems will benefit directly, as medium-temperature reactors will be using water as coolant and higher temperature reactors, lower conductivity material for canning.

Propulsion-unit Purchase

Whether the decision to purchase a propulsion unit from the U.S.A. is desirable or not is a separate issue. Traditional bodies in the shipping world resent dependence upon a foreign power and interpret the decision as a slight against the shipping industry and a formidable set-back to our development effort. With our limited resources, this attitude would appear to place too high a price on national prestige. Certainly a danger exists that without good development grounding in water-moderated reactors, our knowledge will tend to be incomplete and our enthusiasm somewhat tempered. This is a risk, however, that is preferable to the one of failing to produce an operational unit in the near future, particularly if it is considered that a nuclear submarine fleet is essential in our defence programme. There is no reason why the flow of information from the U.S.A. should not stimulate development here and should not lead to the production of a much better propulsion unit in, say, five years' time than would be possible if we tried to go it alone. There is clearly, also, a considerable advantage in having a piece of guaranteed proved machinery on which to experiment rather than merely blueprints. The Government has pointed out that the agreement covers the purchase of one propulsion unit only and does not imply that we are to be dependent on the U.S.A. for our future naval strength.

Patents Agreement

Turning now to the 1956 agreement, the civilian patents position is, of course, complicated by the different relationships obtaining between the U.K.A.E.A. and industry and the A.E.C. and American industry. In the U.S.A. work completed under contract to the A.E.C. is the property of the A.E.C. and is made freely available to companies not engaged in the work. At times the A.E.C. may not be aware (nor particularly interested) in all aspects of the work for which it is paying and the companies individually concerned with the work are, therefore, in an advantageous position as

regards know-how and such information which is not generally distributed. In this country the A.E.A. retains ownership of work completed under contract and almost certainly has a more thorough control of the total experience gained. Present policy calls for the maximum income to be made from such information and the practice of licensing companies to use inventions has grown apace. It is understood that the A.E.A. regards this commercial approach to development as implicit in its mandate. The Atomic Energy Act is not so specific on this point and whereas the A.E.A. will quote established Ministries and research departments as precedents to support its philosophy, it will hasten to emphasize its unique position as an institution in this country to justify taking the commercial approach to extremes. We suggest that the full implications of the present practice have never been fully appreciated by the Government and that a more generous attitude towards industry would greatly simplify procedure, would markedly speed up the flow of information and would encourage and promote the development of the industry during these difficult times without ultimately affecting the taxpayer's pocket. It should, however, be emphasized that although under the agreement concerning patents, American companies have free use of inventions developed in the U.K. whereas British companies are required to pay, should an American company wish to export a piece of equipment to a country where such a patent is in operation, then appropriate fees must be paid. The 1956 agreement contained a clause which provided that in such circumstances there would be no discrimination against an American company but similar conditions would be applied.

One corollary of the A.E.A. operating as a commercial organization is that when the Government negotiates these international agreements it is directly conscious of commercial implications and is unlikely to enter into any disadvantageous agreements which will jeopardize our position in the export market. Certainly, with those negotiated so far, there are no grounds for suggesting that the Government has sacrificed commercial interests on the altar of defence.

Windscale Decision?

WITH the publication of the final report of the Technical Evaluation Committee under the chairmanship of Sir Alexander Fleck (page 338), the A.E.A. is faced with the decision regarding the action to be taken on the two piles at Windscale. As indicated by Sir William Cook at the Press conference on the Report —and later confirmed—No. 1 reactor is definitely a write-off. Certainly, with so much damage to the core, the cost and effort of reconstruction would be vast, and the operation would not be without its hazards. Some cannibalization of a minor nature can no doubt take place: for example, the fans might find a use elsewhere. Otherwise the only solution appears to be to lock the entrances for a very long time and leave it to future generations to decide if it shall remain a permanent monument to the early years of development.

With regard to No. 2, the Report specifies two approaches which can be made to the task of continuing operation. One which is not favoured accepts an incomplete energy release and relies on a high degree of control of the rate of change of temperature within the reactor. This would seriously limit the flexibility of the pile and would no doubt provide a permanent source of worry. The preferred method provides for substantially complete annealing by a slow low-temperature release, followed by a higher-temperature release; both initiated by heated air rather than nuclear energy. This would allow normal operation at slightly reduced power.

Certain modifications to the reactor are considered essential, for example, the provision of a more efficient filter system which would incorporate chemical agents to absorb the iodine, a considerable expansion of the instrumentation facilities and the provision of adequate stand-by cooling with guaranteed power supplies. The additional impedance imposed by the new filters on air flow would not reduce the power of the reactor by more than a few per cent. A detailed costing of the modifications necessary to bring the reactor in line with the Fleck recommendations is in the course of preparation. A figure of £500,000 has been suggested as the probable minimum total.

These modifications are therefore no small item, but on the whole such an expense would appear justified. The plutonium that this reactor would produce has presumably still a large military value, otherwise the decision would not have been taken to modify some of the civilian power reactors to provide plutonium of military grade. It should be noted that the current price in the United States is $30 per gramme. The experience also that would be obtained, not only on the reconstruction, but on the operation of the reactor and its behaviour during a Wigner release, could be of considerable value in completing our knowledge of the behaviour of graphite under irradiation. Having spent so much effort recently on research into graphite behaviour, it would be unfortunate if this could not be completed by operational experience.

An important function of the Windscale reactors which has received little notice following the accident, concerns the isotope production. It is difficult to put an exact economic figure on the value of radioisotope production as pure sales value is somewhat theoretical and does not include the amenity importance of radioisotopes, nor can it take any account of the effect of the present dislocation of supplies. Should Windscale not be restarted, there is also a danger that the materials testing reactors would be overloaded by isotope demands and materials testing programmes would suffer as a result. It is to be hoped, therefore, that the necessary funds and effort will be found and that we can look forward to the start-up of Windscale No. 2 some time next year.

DIGEST...

Surveying Significant News

Exchange of Military Information with U.S. and Sub. Propulsion Unit Purchase Agreed

Congressional opposition is not expected to the recently negotiated U.K./U.S. agreement on the exchange of military information which includes also the purchase of a Westinghouse submarine propulsion unit. Congress may rise before the requisite thirty days are complete, in which case the agreement must lie before the next session for sixty days. Final details on Calder fuel elements to be disclosed but industrial developments are included (see Editorial).

U.S.A.—Euratom Agreement to Assist American Industry in European Power Reactor Field

Congressional opposition is expected to the U.S.A./Euratom collaboration agreement on the grounds of inadequate control and inspection. The agreement envisages the construction in the six Euratom countries of a total of 1,000 MW installed nuclear capacity by 1963 and a joint research and development programme. Main features of the agreement concern long-term credit facilities and generous fuel terms. Capital cost of stations is estimated at $350 M, of which $200 M would be provided by relevant utilities and other European sources of capital and $135 M by the U.S. Government as a loan through the Export/Import Bank, period and rates being quoted at 12 to 20 years at 3½%. The U.S. will guarantee over a ten-year period of operation ceiling costs for fabrication of fuel elements as well as fuel burn-up. 30,000 kg contained U^{235} would be made available to cover the twenty-year operational period; initial inventory amounts to approximately 9,000 kg. This would be sold to Euratom on deferred payment basis with the standard U.S. internal rate of 4% operating. Replacement fuel would be paid for on a current basis. Euratom would be responsible for own safeguards to ensure only peaceful applications of material. A joint research and development programme is to be instituted for a ten-year period, each party contributing $50 M for the first five years, the sum for the second period to be determined later.

U.K.—Euratom Talks

Final discussions between U.K. and Euratom will take place in London in September. Recent talks in Brussels have defined areas of agreement and differences. Understood that outstanding insurance problems are of legal nature only. Inspection problems are complicated by O.E.E.C. and existing bilateral agreements. Fuel ownership during reprocessing also concerned.

Final Windscale Report Published, Reactor No. 1 Definitely a Write-off

Final report on Windscale accident has now been published in the form of a White Paper. The Technical Evaluation Committee has examined steps which can be taken to allow safe re-operation of reactor No. 2. Additional instrumentation and other modifications necessary to No. 2 believed to cost over half a million pounds. A decision is expected shortly on whether this work will be done or whether No. 2 will be abandoned (see Editorial). Reactor No. 1 is now officially to be closed down.

Increased I.A.E.A. Budget for 1959

Budget for 1959 of $5¼ M for I.A.E.A. shows an increase of $1.76 M over that for its first fiscal year, which runs from November 16, 1957, to December 31, 1958. In addition the general fund from which most of the Agency's operational programmes will be financed is to be increased from $250,000 in 1958 to $1½ M in 1959. Decisions taken by Board of Governors in Vienna on July 8.

U.S.A.E.C. Reorganization Postponed, Senate Approval for McCone

Reorganization within the A.E.C. following completion in April of investigation initiated by Strauss is to be delayed pending appointment of new Chairman. A.E.C. has suffered from the resignations of many senior personnel and is at present still awaiting appointment of Strauss' replacement. A Senate Committee has reported favourably on the appointment of McCone as fifth Member of the Board and the Senate will almost certainly approve. Expected then that McCone will be made Chairman. McCone, a Californian shipping executive, is highly regarded by both sides of Congress and by industry and is expected to provide necessary drive and acumen in new position.

U.K.A.E.A. Annual Report

The Fourth Annual Report of the U.K.A.E.A. was published on July 24. The report for the first time details some of the work being conducted at A.W.R.E. on thermonuclear processes. Concurrent with the toroidal experiments at Harwell Aldermaston has been conducting research with straight tubes.

U.S. Process Steam Reactor Proposal

Michigan Chemical Corporation of St. Louis has put up a proposal to the U.S.A.E.C. to build a process heat reactor. The company maintains that the steam could be competitive with that produced by conventional means, an immediate price of 81 cents per 1,000 lb being quoted with a probable reduction to 70 cents as fuel costs come down. This should be compared with present costs with oil as fuel of 92 cents per 1,000 lb. Capital cost of the plant is estimated at $\$2\frac{1}{2}$ M.

Military Plutonium from Civil Power Stations

Modifications are to be made to the Hinkley Point power station in order to allow plutonium of military grade to be recovered, should the need arise. The Government has made this request to the C.E.G.B. (in the words of Mr. Maudling) in order to provide the country at comparatively small cost with a most valuable insurance against possible future defence requirements; the cost of providing such insurance by any other means would be extremely heavy. Production will be in the region of 500 kg per year. The next two C.E.G.B. stations are similarly affected.

Japanese Agreements Ratified

Formal agreements between the British and Japanese Governments were signed in June. Discussions have been under way since last November and have been held up on the question of third-party liability as Japan was anxious to make Britain responsible for this liability during the operational life of the reactor. Japan has now agreed to effect its own insurance. A similar agreement has been signed with the U.S.

Japan Seeks Long-term Credit Facilities

Although the Japan Atomic Power Company has asked for financial assistance from the World Bank for Japan's first nuclear power station project, *Nuclear Engineering* understands request has been rejected and the Bank has declined to make a loan. This is apparently because the company did not issue a general invitation to tender. The Bank's rules preclude a loan in these circumstances. Japan Atomic Power Company now expects to raise the money from U.K. sources and the three consortia will be asked, in addition to the actual tender, to quote their terms for a suitable loan. It would appear that the acceptance of one of the British tenders will now depend on (a) technical evaluation (with the assistance of U.K.A.E.A.) with particular reference to earthquake protection; (b) the tender price; (c) the proportion of work to be handled by Japanese companies; (d) the size of the loan, the interest rate and the length of tenure.

Brazil Seeks Nuclear Power Station Contract in Britain

Brazil is to seek proposals from British companies for the construction of a 200 to 250 MW nuclear power station. It is understood that the President is determined to complete such a purchase before the expiry of his term of office and is at present inclined towards the British type of reactor. Amongst companies known to be in a position and willing to negotiate such contracts from Brazil is SAICOF which has already carried out several large engineering contracts for the Brazilian Government.

B. and W. Join B. and W.

Babcock and Wilcox, Limited have extended their traditional technical collaboration agreement with their American namesakes to cover nuclear energy developments. This is the first tie-up between a member of one of the four consortia building civil power stations in the U.K. (and with comprehensive access agreements) with an American company which is in a similar position.

Inadvertent Criticality Incident at Oak Ridge

Criticality incident at Oak Ridge on June 16 now believed caused by leak of enriched liquor into ever-safe containers in recovery area. Water was added (without mixing) and containers drained into 55 gal. drum. No explosion occurred but reactor produced, pulsed for 4 min. Eight people were involved, maximum and minimum possible doses being 320 and 20 rad.

Reactor News in Brief

Westinghouse 20 MW light water test reactor at Waltz Mill critical.
A.W.R.E. light water assembly HORACE critical at Aldermaston.
Lockheed's critical experiment built by G.E. in operation at Dawsonville, Ga.
Poland's 2 MW pool reactor EVA at Swierk near Warsaw critical.

NEPTUNE

The Admiralty Zero Energy Reactor at Harwell

By J. EDWARDS, B.N.S.S.
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(*A.E.R.E., Chief Physicist, Neptune*)

For the design of the "Dreadnought" submarine reactor, it was essential to have a zero-energy experimental unit for rapid checking of calculations. This article describes some of the mechanical design features and the type of experimental work carried out. The value of the facility is not impaired by the U.K./U.S. exchange agreement.

NEPTUNE, the Admiralty's low-energy experimental reactor in operation at A.E.R.E. Harwell, was built to provide the basic reactor physics information relating to light water cooled and moderated, highly-enriched systems, to guide the design of the "Dreadnought" power reactor, and to assist in the many problems concerned with the calculation of criticality, control, temperature effects and endurance.

The first detailed consideration of a specification for Neptune was undertaken between the Naval Section and Harwell in about April, 1956. At that time, a decision on the design of fuel elements and coolant spaces to be used for the power reactor had not been taken, so there was a need for a particularly flexible facility, able to cater for a wide range of core sizes, and compositions. The reactor had to be constructed so as to enable changes in the core arrangement to be made quickly and measurements of such quantities as neutron spectra, flux distributions, including fine structure, control material effectiveness and temperature coefficient to be made expeditiously and accurately. The time scale for the project as a whole was pressing, and it was particularly necessary that the fissile material should be used in a form that could be rapidly fabricated and also quickly recovered if necessary. The use of water as the moderator and coolant for the power reactor with the consequent small migration lengths of neutrons meant that small spacings had to be employed in the fuel plate assemblies. Accordingly, a high degree of engineering precision was required in the design of Neptune and the associated experimental equipment.

The basic specification for the design, in terms of defining the range of core sizes to be studied, the zero energy fuel element composition, the method of control and shutdown, and other main features was hardened about July, 1956, to enable the design proper of the facility to be commenced by Rolls-Royce Ltd. who, as a member of Vickers Nuclear Engineering Ltd., was employed by the Admiralty as the main contractor for the design and construction of the reactor.

General

The design allows the reactor to be critical with the fuel elements partially submerged in the moderator, when the reactor is controlled either on water height or with a fine control rod. If the reactor is critical with the fuel elements fully submerged in the moderator then the reactor is controlled with a fine control rod only.

Since power level is usually about 1 to 2 watts and only on a few occasions exceeds 10 watts, the problem of "hot" fuel plates and handling difficulties is not serious and the only reactor cooling arrangements needed are for use in work on the measurement of temperature coefficients.

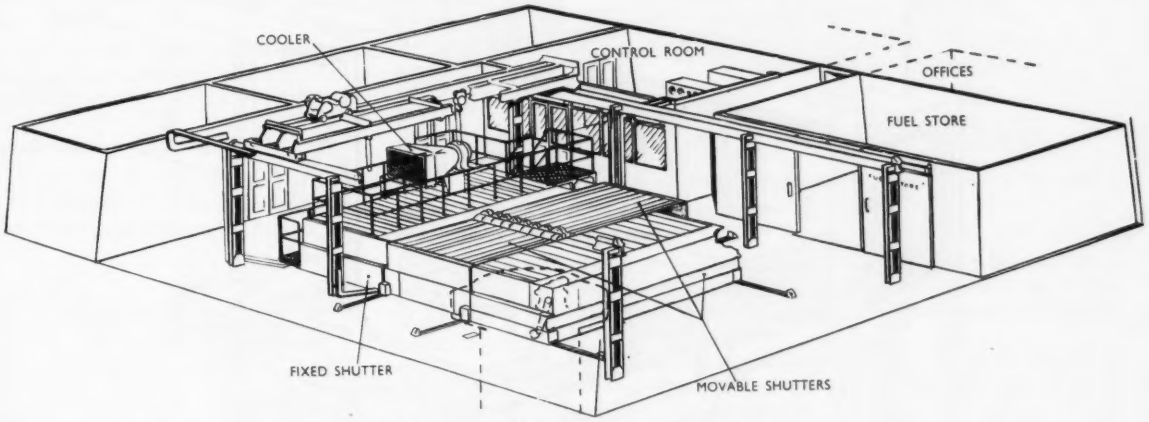


Fig. 1.—General layout of the reactor building.

The reactor is housed in a concrete pit, 27 ft × 15 ft × 24 ft deep, in a hangar-type building some 80 ft × 60 ft, which also accommodates the control room, fuel storage bay, maintenance workshop and three laboratories (Fig. 1). Fig. 2 gives a general view of the reactor. The core is built up inside a cylindrical aluminium tank on a heavy steel structure in the pit. Two horizontal aluminium tanks below the intermediate floor level form the main water storage and dump tanks, and a system of centrifugal pumps enables the water to be pumped from the storage to

the dump tank and thence to the reactor tank. Two large dump valves are fitted to the reactor tank to enable water to be drained rapidly away.

Electric heater banks of some 150 kW capacity and an air-blown cooler system are available for raising and controlling the moderator temperature to the maximum of about 85°C in order to permit studies to be made of the temperature coefficient effects. Higher temperatures cannot be used since the reactor tank is not pressurized.

Fixed and movable concrete shield assemblies some 4 ft thick in total cover the reactor pit. The moving shutters are each mounted on a pair of steel trolleys, each fitted with two double flanged wheels to suit shutter rails laid flush with the floor level of the hangar. The shutters are controlled from a small panel mounted on the guard rails provided on the fixed shield assembly and limit switches are fitted for both inward and outward traversing.

The reactor tank is approximately 8 ft dia × 14 ft overall height, welded from ¼ in. aluminium, and all internal components are made from aluminium with a low copper content, stainless steel, synthetic rubber or plastics, in order to minimize corrosion and avoid undue contamination of the moderator.

A square chamber forming the top of the tank carries the seating for a ¾ in. aluminium lid, which is secured by 12 swing bolts and a clamp ring. This chamber also houses the shafts, bearings, pulleys, etc., associated with the shut-off absorber plates. Locks are provided to prevent unauthorized access to the core and limit switches are fitted to shut the reactor down if the lid is removed. A circular aluminium lattice plate is located centrally at about 1 ft above the tank base. A series of jig-bored holes in the plate provide precise location of the fuel boxes.

Fuel Elements

The fuel is contained in stainless steel fuel boxes (Fig. 3) and several hundred of these are required to build the maximum core size capable of being housed in the tank. The fuel plates are 12 in. long × 3 in. wide × 0.020 in. thick. This size plate bears no particular relationship to the size or shape of fuel elements planned for the power reactor and was chosen on the grounds of speed of fabrication and flexibility in the build-up of differing core sizes.

Some idea of the general accuracy of manufacture required can be gained from the fact that bowing of fuel

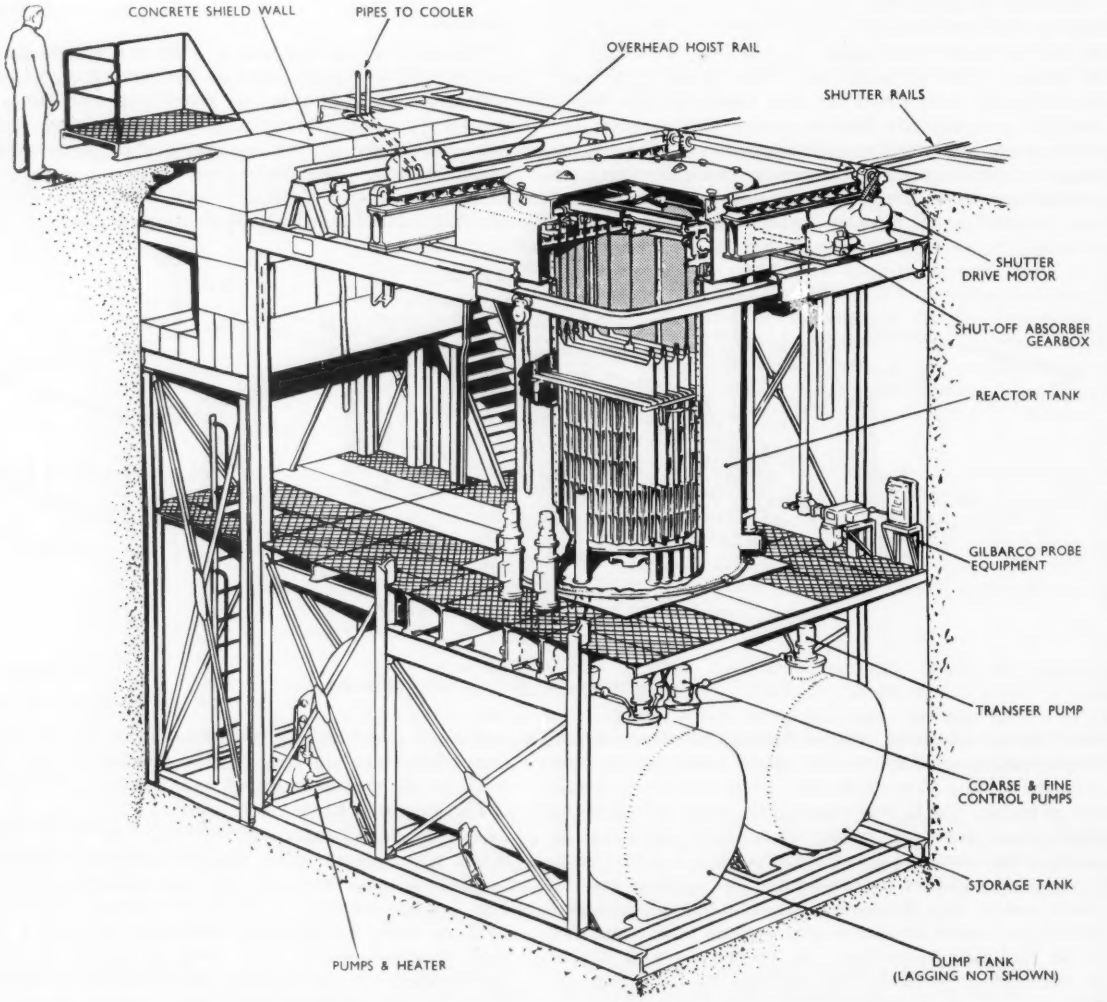


Fig. 2.— Arrangement of reactor in pit showing main vessel and storage and dump tanks.

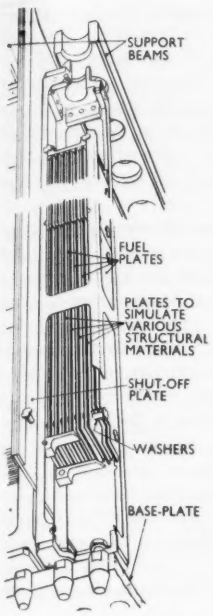


Fig. 3.—Fuel and neutron absorber plate unit.

plates over 1 ft lengths was not to exceed 0.015 in.; the tolerances on thickness, width, and length were ±0.001 in,. 0.005 in., and 0.010 in. respectively.

Fuel is loaded into the boxes in the form of packs of uranium-aluminium alloy plates interleaved with plates of the other structural materials under investigation. Each pack is secured by four stainless steel bolts; the plate spacing is effected by means of high density graded thickness polythene washers. The finished size of the pack is such that it is a good slide fit inside a fuel box and each box can accommodate a number of such assemblies. Fig. 4 shows a typical assembly being built up in the jig. The fuel is locked in position in the box by means of small aluminium bridge pieces.

An aluminium top cap riveted to the box carries a spigot for location purposes in the $2\frac{1}{2}$ in. square aluminium locking bars, which rest on cross beams fitted with locating dowels and rigidly fixed to the vertical ribs. Hollow bushes fitted to the locking bars at the dowelling points give, on removal, sufficient clearance to eliminate cross-binding of the bars on the dowels. The capping strip, secured to each cross beam by two captive nuts, prevents any accidental disturbance of the locking bars. The fuel boxes are arranged on a square pitch on the lattice plate so that after assembly a nominal $\frac{1}{4}$ in. gap exists between rows of boxes in which the shut-off absorbers operate.

Shut-off Absorber System

The shut-off absorber system has been designed to give the maximum fail safe performance should any fault occur in the system and ensures the reactor will shut-down when

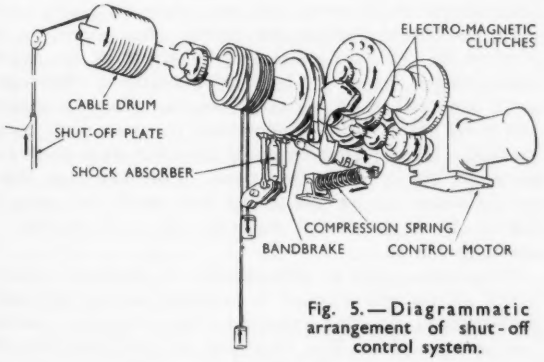
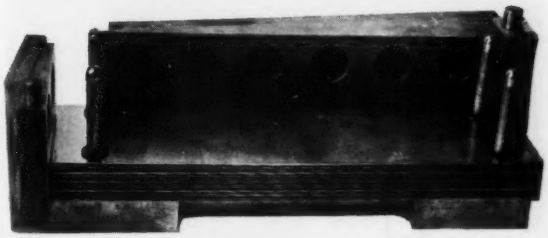


Fig. 5.—Diagrammatic arrangement of shut-off control system.

required, even if an extremely unlikely mechanical failure arises. Six shut-off absorbers are provided in the form of large sheets of cadmium just under 1/32 in. thick, clad on either side with aluminium by means of the Araldite hot-bonding technique. The absorbers are divided into two banks of three sheets, and are inserted in alternate gaps

Fig. 4.—Building up a typical plate pack in a jig.



between the locking bars and rows of fuel boxes. Each sheet is stiffened along its vertical edges by stainless steel strips riveted in position and is suspended at the upper corners by two flexible stainless steel cables. Each pair of cables is fitted with adjusting turnbuckles, and connected to a bridle fitted to the corner of the sheet, serving as a load-equalizing device. Snubbing devices are

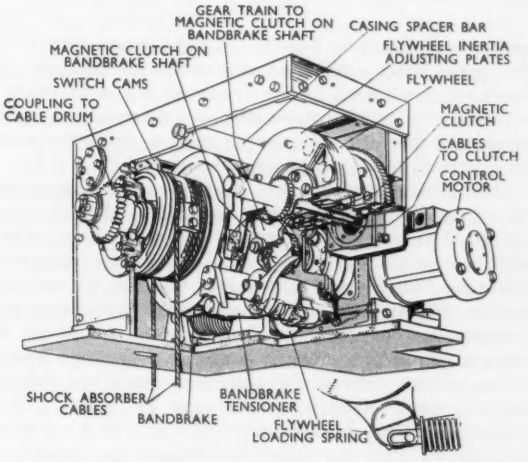


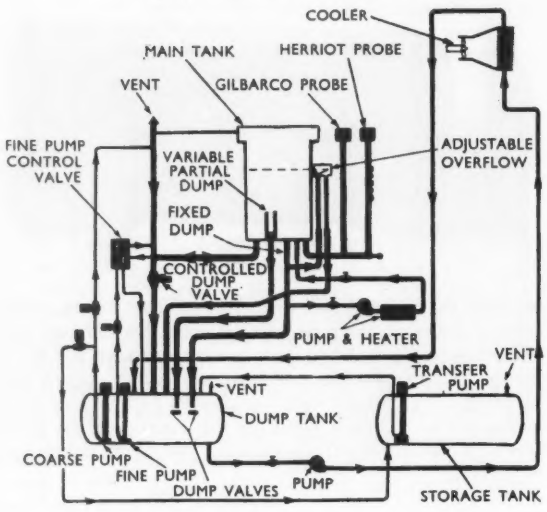
Fig. 6.—General arrangement of gearbox unit for shut-off control system.

fitted in certain of the struts supporting the bottom lattice plate; these serve to cushion the shock should any of the absorber control or suspension fail and so prevent serious damage to the reactor.

A main winding shaft with a number of grooved pulleys to take the suspension wires is provided for each bank of absorbers and mounted in the square box portion of the reactor tank. Each main winding shaft is connected by a fully floating gear coupling type, intermediate shaft, which passes through the square side of the reactor tank to its appropriate control box.

The absorber control system is shown in its essentials in Fig. 5. The absorbers drop into the core under gravity and provision is made in the system to allow an initial free drop followed by a progressive braking period over approximately half the travel to reduce the energy of the sheets to a level at which they can be safely snubbed in the last 4 in. of travel without damage. A small three-phase a.c. motor, complete with built-in magnetic brake and worm reduction gear, is mounted externally on the baseplate and drives the gear train inside the gearbox through a flexible coupling. The internal design of the

Fig. 7.—Schematic flow diagram.



gearbox is shown in Fig. 6. A rope drum provided on the main shaft takes two contra-wound separate steel ropes, each clamped to the centre of the drum, both of which terminate in bob-weights which serve to keep the ropes taut and also function as stops to limit the inward and outward travel of the absorber plates.

On operating the "raise" button on the control desk the magnetic clutches are engaged and the motor energized to start to wind up the absorber. The "down" stop bob-weight begins to travel downwards, releasing a hydraulic shock absorber which is reloaded by means of springs, the "up" stop bob-weight begins to move upwards towards its stop position. The flywheel shaft rotates and turns a camshaft causing a buffer to move and become spring loaded. When the absorbers reach the fully-out position, switches on a layshaft stop the motor and the magnetic clutches hold the absorbers and braking system in position, with the "up" bob-weight just clear of its stop. If the "release" button is operated the magnetic clutches are released, the absorbers start a free fall into the core and turn the main winding shaft. The flywheel and camshaft unlock and, under the action of the buffer spring, the camshaft drives the flywheel and starts to take up slack in the band-brake. The flywheel overhauls and the spring system of the band-brake applies the latter smoothly until flywheel rotation ceases. The direction of rotation of the flywheel then reverses due to the pull of the spring and the brake is progressively released. By this time the "down" stop bob-weight has contacted the hydraulic shock absorber in the last four inches of travel and snubs the absorber sheets, finally coming to rest on its stops. The time from operation of the release to the absorbers reaching four inches from the bottom position is adjusted to be 1.2 sec.

This system has proved particularly effective and constant in its operation as determined by timed drops of the absorbers. Its smooth actuation and avoidance of heavy shock loads will add appreciably to the life of the system.

Water System

The water flow system for the reactor is shown in Fig. 7. The water dumping arrangement consists of two 7 in. dump valves which are closed electrically and held by an electromagnet. On release of the electromagnet the valve opens under its own weight and the water pressure. The full dump valve is connected directly to the bottom of the reactor tank and gives complete drainage. The partial dump valve is provided with a removable standpipe inside the tank to lower the water level to a predetermined position. A control dump pipe line is also provided which leads through an orifice plate and magnetic valve to the dump tank.

Water may be transferred from the storage to the dump tank by means of a centrifugal transfer pump. A second similar pump can deliver water from the dump tank to either the reactor tank or the storage tank, depending on the closing and opening of the appropriate magnetic valves. This "coarse" pump delivers water at a maximum speed equivalent to about 3 cm/min change in water level in the reactor tank. This maximum pumping speed can be reduced by means of an orifice plate in the delivery line.

A third centrifugal pump with a lower pumping speed delivers water from the dump tank to the reactor tank through a fine control valve. When moved in one direction, this allows the delivery rate from the "fine" pump to be varied continuously from no-flow up to a maximum value of 1 cm/min rise in water level in the reactor tank, and when moved in the opposite direction allows water

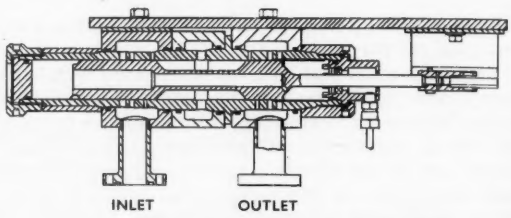


Fig. 8.—Piston valve used for fine control.

to flow back to the dump tank under gravity at a rate variable up to a maximum of 1.25 cm/min fall in water level. This valve can be used to control the reactor by varying the water height when the core is critical, with the fuel elements partially submerged beneath the water level.

A section of the fine control valve is shown in Fig. 8. The valve is of the spool type and when the piston valve is in the central position the reactor tank connection is blanked off from the other two by virtue of the piston lands, which close off the feed and drain ports. When the valve is moved in one direction the feed ports are opened and water passes to the reactor tank, the drain ports being blanked. Opposite movement of the valve opens the drain ports and blanks off the feed ports. Feed and drain holes in the sleeve are so positioned that when the valve is moved from its central position, the port opening is gradually varied.

The piston valve is operated by an extension spindle which passes out through a synthetic rubber seal and terminates in a guided crosshead which is used to operate interlock switches. The crosshead is connected through rods and bell cranks to a handle mounted on the control desk. As a "dead man's handle" device, a push-button is fitted to the control handle and has to be depressed before the magnetic valve controlling the feed line from the fine pump to the control valve can be opened.

In the unlikely event of the failure of all interlocks intended to cut off the flow of water, an adjustable weir

controls the maximum level of water which can be pumped into the reactor tank.

Two water level pipes are provided connected via a common manifold at the base to the reactor tank. One pipe accommodates a Herriott probe, of a conductivity type which indicates changes of water level to an accuracy of about ± 0.1 mm. The depth is displayed on an indicator on the control desk. The second pipe accommodates the "Gilbarco" probe which provides a coarser level indication with an accuracy of about $\pm 2\frac{1}{2}$ mm, and is displayed on the main instrument panel. A coarse level switch is also provided to limit the moderator height to which the coarse pump can be used.

Fine Control Rod

A fine control rod can be used to control the reactor if required. This consists of a plate of neutron-absorbing material suspended in the gap between fuel boxes on a stainless steel wire with a winding drum and gearbox mounted outside the reactor tank. The control rod gear is driven by a variable-speed electric motor operated from the control desk. The pulley system above the core allows this rod to be mounted in any desired position in the core.

Neutron Source

A radium-beryllium neutron source with an output of 5×10^6 neutrons/sec is used, contained in a platinum cylinder $\frac{1}{4}$ in. dia., and 3 in. long. This is mounted at the end of a stainless steel tube suspended from a stainless steel wire fitted over pulleys to a source winding gearbox outside the reactor tank. A 6 in. dia. lead cylinder, clad in stainless steel, is clamped to the fuel element locking bars, and positioned so that the source tube passes through the centre of the lead shield and slides into a channel formed by the adjacent corners of four fuel elements. When the source is fully withdrawn from the core, it is positioned in the centre of the lead shielding; this reduces the gamma radiation due to the source to a level sufficiently low to permit access to the reactor tank. The position of the source and the shield on the locking bars above the core can be varied to suit the experimental requirements.

Instrumentation

The nucleonic instrumentation for Neptune is largely conventional in the nature of the units employed, although the arrangement has some novel features largely arising out of the need to provide adequate neutron flux monitoring and shut-down trip protection at all stages of an approach to critical, including the initial condition when there is no water moderator in the main tank of the reactor.

There are seven neutron flux measuring channels in all. Five channels use an ion chamber of the RC 1 type with an enriched boron coating as the detector followed by a d.c. amplifier; the remaining two channels use a $B^{10}F_3$ proportional counter followed by a high-gain amplifier and pulse ratemeter. Briefly, the arrangement of these channels is as follows:—

(a) Three linear shut-down d.c. channels each with an ion chamber and linear amplifier with a high level flux trip which can be set over the range of 10% to 100% of a maximum flux of 2×10^7 neutrons/cm^2, sec measured at the ion chamber.

(b) A multirange linear d.c. channel with lead-shielded ion chamber. The display of the control desk recorder covers five decades with a maximum flux of 10^7 neutrons/cm^2, sec at the ion chamber. The output from this linear channel is fed into a deviation amplifier so that the scale may be magnified at any selected point by 10 or 100 times.

Fig. 9.—Control desk and instrument panel.

(c) A wide range logarithmic d.c. channel with a lead-shielded ion chamber. The amplifier covers the flux range 800 to 10^7 neutrons/cm^2, sec and the output is fed into a period meter with a short period trip.

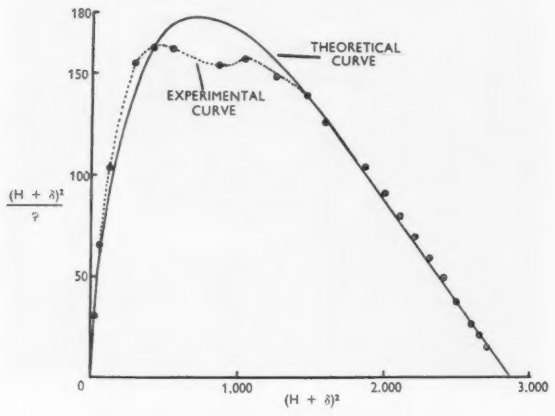
(d) Two pulse-counting channels using $B^{10}F_3$ proportional counters (type 12 EB 40) for low neutron flux measurements. The output from the amplifier is fed to a logarithmic ratemeter with low and high flux warning followed by a period meter with a short period trip.

The ion chambers are encased in waterproof plastic jackets and mounted in the main tank in the water reflector adjacent to the loaded core. Since flexibility is required in the size of the core, the ion chamber mountings are readily adjustable. The position of the chambers is chosen so that there is no material within 10 cm of the core boundary to disturb the reactivity of the system, and so that all d.c. channels indicate their maximum flux at the same reactor power. Some adjustment in sensitivity is also provided so that the output from the three logarithmic channels when presented on the control desk recorder will be consistent with the wide range linear channel. The lead shielding round the ion chambers for the two wide range channels is to reduce the error due to gamma radiation from the core when running the reactor at low power following operation at a high power.

The proportional counters for the two pulse channels are mounted in horizontal tubes immediately beneath the lattice plate (Fig. 2); so that these channels will indicate a finite neutron flux even when there is no water in the tank. The counters are surrounded with polythene, to make them sensitive to fast neutrons from the Ra-Be neutron source incorporated in the reactor.

When the reactor is running at normal power, the neutron flux at the proportional counters would cause a rapid deterioration in their performance, and in order to protect them, they may be motored out to a position of lower flux; this is normally carried out when the flux at the counters reaches 10^4 neutrons/cm^2, sec. At this power level, the d.c. logarithmic channel will be giving an adequate reading. A switch is provided so that either the d.c. or a pulse logarithmic channel may be selected to give protection against a short period excursion; this selected channel is displayed on the control desk recorder. Interlocks are arranged to ensure that the pulse counters must be fully in

Fig. 10.—Typical approach plot obtained.



before start-up can commence and a neutron flux greater than 3 neutrons/cm², sec indicated on the ratemeter. The counters can only be motored out after the changeover to the d.c. logarithmic channel has been made.

Four channels are provided to monitor continuously the radiation levels in the vicinity of the reactor. Three of these channels are sensitive to gamma radiation and indicate on a logarithmic scale from 0.1 to 10^4 m.p.l. Two of the associated ion chambers are in the reactor pit and the third is on top of the fixed shield. The fourth channel is sensitive to slow neutrons, with an indicated logarithmic range of 0.1 to 10^3 m.p.l. and the associated ion chamber is situated near the control room.

The control desk and instrument panel are shown in Fig. 9. The control buttons for the water system are incorporated in a schematic diagram of the reactor immediately in front of the operator and the wide range linear channel and the logarithmic channels are presented on the recorders on either side of the desk. The instrument panel contains most of the physical instrumentation of the reactor, including the water depth and temperature gauges. The order signs at the top of the panel give the reactor state and any fault indication in a quickly interpreted manner.

Approach to Critical Procedure

The manner in which the reactor is operated is well illustrated by the sequence of events during an approach to critical. The interlocks are arranged so that reactivity may be added to the system by only one method at a time. Also the speed by which reactivity may be increased is limited so that, should criticality occur unexpectedly, the automatic trip system will shut the reactor down without the occurrence of any large power excursions. For this reason the reactor is always operated with the shut-off absorbers fully removed from the core.

Before the approach can commence, it is necessary for the main tank lid to be secured and the concrete shielding shutters closed. The pulse channels must be motored fully in and indicating a finite neutron flux. The sequence of events is, then:—

(i) Close the main dump valve.
(ii) Raise the primary bank of shut-off absorbers. (Duration 10 minutes.)
(iii) Raise the secondary bank of shut-off absorbers. (Duration 10 minutes.)
(iv) Raise the water level in the reactor tank with the coarse pump. This pump has a maximum speed equivalent to 3 cm of water height in the reactor tank per minute and for small cores it may be throttled down with an orifice plate. The pump is started by push-button on the desk and runs for a preset interval varying between 1 and 5 minutes. This pumping is continued until the level of the top of the partial dump stand pipe is reached (see Fig. 7), when a water level switch is operated and the interlocks prevent the coarse pump from running. The partial dump level may be above the bottom of the loaded region of the core and is selected to give a reasonable degree of shut-down in the partial dump condition.
(v) The partial dump valve is closed. As an added protection, this also prevents the coarse pump operating.
(vi) The water height is raised by the fine pump and the flow may be varied continuously by the fine control valve. A button on the handle controlling this valve must be depressed to open a magnetic valve before the water will flow into the reactor tank. The maximum pumping speed is equivalent to 1 cm of water height in the reactor tank per minute. This maximum speed may be reduced by means of an orifice plate inserted in the delivery pipe. If the reactor will become critical with the fuel elements partially flooded, the maximum fine pumping speed must be restricted to give an increase in reactivity of less than 1% per minute at criticality.
(vii) If the core is critical when fully flooded, the fine control rod must be raised to reach criticality. This rod will control not more than ½% in reactivity and the value will be dependent on the shape and size of the rod and the position selected in the core. The control on the desk gives a choice of three speeds in either direction with a maximum speed of movement of 6 in. per minute. The position of the rod is indicated by two magslip recorders.

When the reactor is near critical with a neutron flux of approximately 10^4 neutrons/cm², sec on the wide range linear channel, the neutron source is raised out of the core

Neptune

Le " Neptune " est le groupe d'essai à faible énergie de l'Amirauté Britannique installé à l'Etablissement de Recherches d'Energie Atomique de Harwell pour résoudre les problèmes de base de la conception du réacteur d'énergie " Dreadnought." La caractéristique essentielle de la conception est représentée par la souplesse de la disposition du noyau, de sorte que des mesures comparées des spectres de neutrons, de la distribution du courant, de l'efficacité du contrôle et du coefficient de température puissent être rapidement prises sur des types de noyau différents. Le réacteur est modéré à l'eau légère, et est alimenté avec de l'uranium hautement enrichi comme combustible; si besoin est, le contrôle pourra être effectué par la modification du niveau du modérateur. Etant donné que le réacteur est d'énergie zéro, le refroidissement n'est pas requis pour le fonctionnement. Le nécessaire pour le chauffage et le refroidissement est, toutefois, prévu pour les travaux sur coefficients de température.

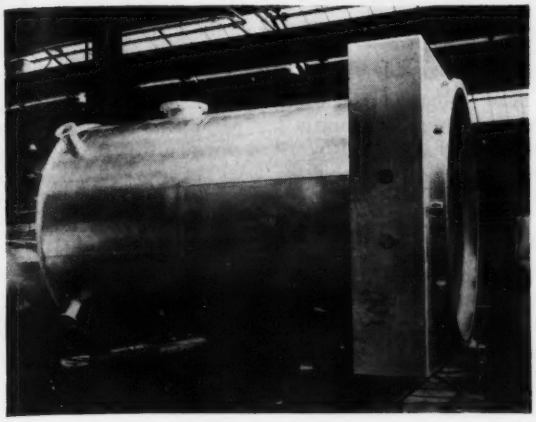
Neptun

" Neptune " ist die auf Veranlassung der Admiralität im Atomic Energy Research Establishment Harwell aufgestellte Versuchsanlage für weiche Strahlung, deren Zweck Lösung der beim Bau des " Dreadnaught "-Leistungsreaktors auftretenden grundlegenden Probleme ist. Das wesentliche Konstruktionsmerkmal ist Anpassungsfähigkeit der Cor-Anordnung, um vergleichende Messungen von Neutronenspektrum, Flussverteilung, Regelungseffekt und Temperaturkoeffizient für verschiedene Cor-Ausführungen schnell vornehmen zu können. Der Reaktor ist leichtwassermoderiert und wird mit stark angereichertem Uran betrieben. Im Bedarfsfall kann die Regelung durch Aendern des Moderatorniveaus erfolgen. Da es sich um einen Nullenergiereaktor handelt, wird für den Betrieb keine Kühlung benötigt. Es sind aber Heiz- und Kühleinrichtungen vorgesehen, um Untersuchungen über Temperaturkoeffizienten durchführen zu können.

Neptune

" Neptune " es la unidad experimental de baja energía del Almirantazgo británico instalada en el Establecimiento de Investigaciones de Energía Atómica de Harwell para solucionar los problemas básicos de diseño del reactor de energía " Dreadnought ". La característica esencial del diseño es la flexibilidad en la disposición del núcleo, de modo que se puedan hacer rápidamente sobre modelos distintos de núcleo las mediciones comparativas de expectra neutrónica, distribución de flujo, efectividad de control, y coeficiente de temperatura. El reactor es moderado a agua ligera, y el combustible empleado es uranio altamente enriquecido. El control puede llevarse a cabo, en caso necesario, mediante la alteración del nivel del moderador. Desde que el reactor es de energía cero, no hay necesidad de enfriamiento para la operación. Sin embargo, hay provistas disposiciones de calentamiento y enfriamiento para trabajo sobre los coeficientes de temperatura.

Fig. 12.—The aluminium core vessel during manufacture.



and the pulse counters withdrawn to a lower flux. The approach to critical always occurs at carefully controlled speeds and the duration of an approach for a typical core is about 90 minutes.

On full shut-down, both banks of absorbers fall into the core under gravity and both dump valves are opened. On partial shut-down the secondary bank of absorbers falls into the core and only the partial dump valve is opened. For calibration purposes it is possible to drop a bank of absorbers without opening either dump valve.

For maintenance purposes, it is possible to break this approach sequence and operate any pump, valve or motor on its own as selected by a key switch.

Experimental Measurements

An essential measurement on any new core arrangement is to determine the critical size. Although adequate automatic trip protection is provided by the instrumentation, for reasons of safety it is desirable to take special precautions when an approach to critical is being made with a new core assembly. In Neptune multiplication measurements are made whilst the height of the water moderator in the reactor tank is increased. Fig. 10 shows a typical approach plot obtained by measuring the neutron flux with a small fission chamber mounted near the centre of the core. The neutron source which was also in the core and the fission chamber were raised to maintain the source and detector in the horizontal plane through the centre of the flooded portion of the core. This approach plot allows the critical height to be predicted with confidence before criticality is reached.

The water handling arrangements have proved very successful in operation and the water height in the reactor tank can be set to within 1/10 of a millimetre of a desired position. When all valves are closed, the leakage rate from the reactor tank is negligible so that full use can be made of a fine control rod even with a core critical when partially flooded.

Whilst the measurement of criticality is essential, a wide variety of measurements must be made to reach a full understanding of the physics of the system and provide the data necessary for the design of the power reactor.

Many of the measurements fall into the following categories:—

1. Surveys of the neutron flux distribution including measurements of the pronounced flux peaking which occurs near a water hole in a light water moderated reactor. These measurements can be made with either neutron sensitive foils or small fission chambers. Some small fission chambers with external dimensions of ½ in. × ⅜ in. × ⅛ in. have been developed for this purpose.
2. Investigation of the neutron spectra in different regions of the core using detectors preferentially sensitive to neutrons of differing energy.
3. Calibration of the reactivity scale with changing water height and the calibration of fine control rods. This may be made by kinetic measurements assuming the proportion of delayed neutrons.
4. Measurements of the temperature coefficient of reactivity over the range 20°C to 85°C.
5. Comparison of effectiveness of different neutron absorbing control materials including a study of materials which are good absorbers of epithermal neutrons.
6. Investigation of the effect of large areas of absorbing materials inserted into the reactor.

Fig. 11.—Looking down into the reactor vessel.

Many of these experiments require special care in the construction and positioning of equipment since the flux peaking effects can give rise to large flux gradients in the core. Equipment is available to move fission chambers in the core either horizontally or vertically in the gaps between fuel elements by remote operation outside the reactor shielding.

For ease and speed of operation, equipment can be brought up through an access port in the lid of the reactor tank and between the concrete shutters. Special blocks on the face of these shutters can be removed to create a gap. In this way foils of materials with a short half life can be inserted and removed from the core whilst the reactor is running. A chute used for this purpose can be seen in Fig. 11.

As previously mentioned, the main contractors for design and construction were Rolls-Royce Ltd. Elliott Brothers (London) Ltd. were the sub-contractors responsible for the detailed design, manufacture and installation of the instrumentation and electrical power supplies. The aluminium tanks were fabricated by the A.P.V. Co. Ltd. Head Wrightson (Teesdale) Ltd. were responsible for the complete erection of the reactor on the site. The A.E.R.E., Harwell, was closely concerned with the design at all its stages and provided much advice on the instrumentation and safety requirements. The major task of fabricating the uranium-aluminium alloy fuel plates was

carried out by the Metallurgy Division at Harwell. The progressing of the facility was the responsibility of the Admiralty staff assisted by A.E.R.E. staff.

The operation of the reactor to meet the experimental requirements is carried out by Harwell staff, and a joint team of Harwell and Admiralty scientists, together with physicists from Rolls-Royce and Vickers-Armstrongs, carry out the experimental programme. The construction of Neptune has been very much a co-operative effort, and the fact that this reactor, despite its complex engineering features and an elaborate instrumentation specification, first went critical on November 7, 1957, only some 16 months from the start of the design proper, is a tribute to the energy and efficiency of all those concerned.

Acknowledgments

The authors are indebted to the Admiralty and the Atomic Energy Authority for permission to publish this article, and to Rolls-Royce Ltd. for many of the drawings and sketches reproduced.

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CERAMIC FUELS—

Properties and Technology

By
R. W. NICHOLS, B.Met., A.I.M.
(*U.K.A.E.A., I.G. Culcheth*)

There is a growing interest in refractory compounds as nuclear fuels, and this article discusses the properties and manufacture of the more interesting materials. Dispersions such as cermets are not included: their properties are often similar to those of their major constituent.

THE advantages anticipated from the use of ceramic fuels, instead of metallic,[1] are greater dimensional stability in the reactor, resulting from absence of such irradiation effects as swelling and wrinkling; greater resistance to attack by the particular coolant or canning material; higher permissible fuel temperatures as a result of higher melting points and absence of low temperature phase changes. Careful selection from the wide range available is, however, necessary to minimize attendant disadvantages. Some of the possible materials with their melting points and densities are shown in Table 1.

To avoid the need for excessive enrichment a large number of uranium atoms per unit volume of fuel is desirable; this requires a compound of high uranium content coupled with a high density. Similarly, the competitive neutron absorption cross-section of the non-fissile components of the compound should be as small as possible. These factors alone have resulted in most interest being shown in certain oxides, carbides and silicides of uranium and similar compounds in the thorium and plutonium systems.

Owing to the relatively brittle nature of most of the ceramic fuels, they require independent support and cannot be used as structural members, hence their mechanical properties are not of very great interest. The physical properties of chief interest are thermal conductivity and thermal expansion, both of which can affect the central fuel temperature; the latter indirectly by altering the clearance between fuel and can.

Information on the effect of alloying additions is very limited; minor additions are usually made to ease fabrication.

URANIUM DIOXIDE

Of all uranium compounds, most attention has been given to the oxide UO_2, which shows a reasonable density, somewhat lower than the carbide and it can, in practice, be manufactured into shapes approaching theoretical density. It shows an isotropic structure with a high melting point, good strength up to high temperatures, and freedom from low-temperature phase changes. It has been favoured because of its inertness to such reactor coolants as pressurized water, hydrogen and carbon dioxide at high temperatures. However, because of its low thermal conductivity, it has to be used in relatively small sections, to avoid excessive centre temperatures at realistic heat ratings. It is also brittle, and subject to cracking under reactor conditions.

The Uranium-Oxygen System

The uranium-oxygen system is one of considerable complexity, details of which have not been completely resolved. The lowest oxide UO is apparently only found in thin films or as inclusions in metallic uranium, or in the presence of carbide or nitrogen within the lattice. The dioxide can exist with a range of compositions, from UO_2 to $UO_{2.2}$ the extra oxygen atoms being held interstitially. The structures obtained in such oxides are dependent on the temperature[2]; at about 300°C they consist of mixtures of two phases UO_2 and U_3O_8, whilst the oxygen content of the lower oxide increases to $UO_{2.15}$ at 850°C (Fig. 1).*

TABLE 1
Uranium densities and melting points of some uranium compounds

Compound	Uranium density g/cm³	Melting point °C
U_6Fe	17.0	815
U_6Ni	16.9	790
U_3Si	15.0	930
UN	13.5	2,650
UC	13.0	2,350
U_2C_3	12.0	1,775 (decomposes)
UB_2	11.8	>1,500
U_3Si_2	11.3	1,665
UC_2	10.6	2,500
UO_2	10.5	2,800
US	9.6	>2,000
USi	9.3	1,600
UNi_2	9.0	985
UB_4	7.9	>1,500
USi_2	7.3	1,600
βUFe_2	7.0	1,235
U_3O_8	6.7	>2,500

On heating in oxygen at temperatures above 400°C there is a structural change to U_3O_8 with associated decrease in density; consequently a non-oxidizing atmosphere must be used in all fabrication processes to avoid cracking of massive components. At higher temperatures, UO_2 is the stable phase even in an oxidizing atmosphere, and this has permitted the use of the steam sintering process (q.v.). The composition of a sintered compact depends on the composition of the initial powder and on the fabrication process; in general with non-stoichiometric powders there is a loss of oxygen content on sintering in an inert atmosphere.

Manufacture of UO_2

Uranium dioxide powder can be produced by several different methods, most of which use an aqueous uranyl nitrate solution as the raw material. After precipitation as uranium peroxide or ammonium diuranate, conversion to UO_3 or U_3O_8 is achieved by heating in air or steam. The higher oxides can then easily be reduced to UO_2 by heating in hydrogen to temperatures between 500 and 800°C. The particles of UO_2 so formed consist of agglomerates of crystallites, and it is found that the size of the particles depends on the higher oxide used and the temperature of reduction; higher reduction temperatures resulting in larger particles and crystals[3] (Fig. 2). Because of this, powders prepared under different conditions show different sintering behaviour. The composition of the powders immediately after the reduction process may be $UO_{2.0}$, but exposure to air even at room temperature causes oxidation which occurs more rapidly the finer the particle size of the powder. Powder particles of about 1 micron will oxidize to about $UO_{2.02}$ after one month in air at room temperature[4] whereas a powder of particle size 0.06μ reaches $UO_{2.15}$ in one day.

*Line illustrations are on pull-out facing next page.

Fabrication of Solid UO_2

Dense fuel element shapes can be produced by a variety of methods, such as slip-casting, extrusion, hot-pressing and even by swaging in a metal tube. This last process can produce bulk densities of 9-9.5g/cc without high temperature treatment. The principal technique so far used has, however, been the sintering of shapes produced by cold-compacting either in a steel die or hydrostatically. The UO_2 powder is first brought to a suitable size range, either by control of the process of manufacture or by ball milling. Frequently a small amount of a solid lubricant is blended into the powder to ease pressing, although this can lead to reduction in density of the finished product. The particle size of the powder can have an important effect on the finished density[5], as indicated in Fig. 3. Sintered density shows a more limited dependence on pressing pressure and values of 10 to 20 ton/in.^{2} are typical.

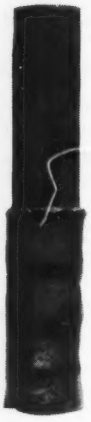


Fig. 5.—UO_2 cylinder partly machined (6) by tungsten carbide tool using soluble oil coolant; cutting speed 20 ft/min, feed 0.007 in/rev, depth of cut $\frac{1}{16}$ in.

The sintering, in an inert atmosphere or vacuum, of powder of exactly stoichiometric $UO_{2.0}$ composition or with only very small amounts of excess oxygen requires high temperatures (1700-2000°C) in order to achieve high-density products. This approach has been used in general in America, the sintering temperature being kept as low as possible within this range by use of very fine, surface-active powders, and in some cases TiO_2 additions. In this country high densities have been achieved[4] by using non stoichiometric oxide powder and sintering at lower temperatures (about 1400°C) in an argon or nitrogen atmosphere, since it was found that the presence of excess oxygen at the sintering temperature increased the rate of sintering. The bulk density is dependent (Fig. 4) on the sintering temperature.[6] Arenberg and John[7] have shown that the use of a steam atmosphere permits the sintering of $UO_{2.0}$ at 1400-1500°C by providing excess oxygen atoms. In this case it is necessary to change over to an inert or reducing gas on heating to or cooling from 1400°C, to avoid cracking as the result of the conversion of the compact to higher oxides at low temperatures. If so required, the dense compacts of non-stoichiometric oxide produced by the British route can be reduced to $UO_{2.0}$ by a final hydrogen or CO reduction treatment, for example at 1200°C. This results in a small decrease in density e.g. from UO_2 10.75 g/cc to $UO_{2.0}$, density 10.16 g/cc.[4]

The machining of sintered compacts is usually achieved[6] by wet grinding, care being necessary to avoid cracking of the specimen but machining with a tungsten carbide tool is possible (Fig. 5). In general, non-stoichiometric material machines more easily than hydrogen-reduced material. Holes can be drilled with tungsten carbide tools, or by ultrasonic techniques using boron carbide in paraffin as an abrasive fluid and a mild steel tool. As is usual with work on uranium powders, it is necessary to take precautions to avoid ingestion or inhalation of fine particles.

An interesting alternative method of preparation is by warm-pressing of non-stoichiometric oxides at 800°C. Densities of 10.6 g/cc have been obtained from $UO_{2.20}$ pressed at 10 ton/in^2. Greater dimensional accuracy is obtained because of the avoidance of the somewhat variable shrinkage on sintering, and a tolerance of less than 0.001 in. on diameter is claimed.[4] This may be a convenient process for producing long rods or plates.

Physical Properties

As indicated in the preceding sections, the bulk density of UO_2 components is dependent on many manufacturing variables. For fuel element material, room temperature values in excess of 10.4 g/cm^2 (i.e. 95% theoretical density) can be considered typical. Another property which can vary greatly from one sample to another is thermal conductivity. As in other ceramic materials which are somewhat porous in their manufactured state, thermal conductivity, especially at low temperatures, is dependent on density and a linear increase with increase of density is generally assumed.

The process of thermal conductivity in UO_2 is largely one of lattice vibration, unlike the electronic conduction which occurs in metals. This process is easily interfered with by lattice disturbances, and the thermal conductivity is thus markedly affected by impurity atoms. In non-stoichiometric UO_2 the excess oxide atoms can produce lattice strains which would be expected to reduce thermal conductivity. In measurements made at Culcheth Laboratories[6] the average thermal conductivity of several specimens of $UO_{2.16}$ (density 10.8 g/cm^3) was found to be 0.008 cal/cm, sec°C at 60°C, whereas stoichiometric UO_2 of average density 10.0 gave values of 0.02 cal/cm sec°C in the same apparatus. The thermal conductivity of any specimen of UO_2 however, markedly decreases with increase of temperature (Fig. 6), and 0.003 cal/cm sec°C is frequently quoted as an average value applicable to the temperature range from 600°C to the melting point of UO_2.

The effect of irradiation in disturbing the perfection of the lattice can also be expected to reduce the thermal conductivity. In an experiment by Flinta[8], UO_2 of 10 g/cm^3 was irradiated at 350°C. After an irradiation dose of only 2.2 x 10^{15} nvt the thermal conductivity was only 0.0048 cal/cm sec°C (at 350°C) as compared with an assumed unirradiated value of 0.0155 cal/cm sec°C. There were some fluctuations in thermal conductivity with further irradiation although the general tendency was for further decreases to occur. Apart from any direct effect of irradiation on lattice conductivity, reactor conditions can also lead to a decrease in bulk conductivity due to cracking of the ceramic material.

Another physical property of interest is thermal expansion, and different determinations are not markedly different (Fig. 7). The coefficient of thermal expansion increases up to temperatures of 400°C and is then relatively constant from 400°C to 900°C. Values of 10 x 10^{-6} per °C are typical for the lower temperature range (27-800°C), whereas the average value over the range 800-1260°C has been given[5] as 13 x 10^{-6}.

Determinations of specific heat are useful in that they provide information for calculating the heat capacity of a reactor core. Several determinations have been made in various laboratories and consistent results obtained even on materials from different sources. The values shown in Fig. 8 based on the work of Kelley[9] are typical.

There is a considerable variation in the values quoted for the melting point of UO_2. This variation may arise in part from real differences due to differences in composition, but there are considerable practical difficulties in such high temperature determinations. The values obtained in recent determinations range from 2405 ± 21°C (Ackerman)[10] to 2878 ± 22°C (Lambertson and Mueller).[11] The former value was obtained in effusion measurements to determine

(*Continued on page* 329.)

Nuclear Engineering
DATA SHEET
No. 10. Ceramic Fuels

A. URANIUM DIOXIDE

(Values in general refer to stoichiometric material)

Crystal structure .. .. Cubic, CaF_2 type
Lattice parameter (25°C) .. .. 5.468 Å ($UO_{2.0}$)
Theoretical density (25°C) .. .. .. 10.97 g/cm³
Uranium density (25°C) .. .. 10.5 g/cm³
Thermal neutron absorption cross section .. 0.165 cm⁻¹
Melting point (26) .. .. 2,750±40°C
Specific heat (see fig. 8) (9)
$C_p = 0.071 + 6.10^{-6} T - 1466\ T^{-2}$ cal/g, °K (T in degrees K)
in range 0–1,200°C, average value 0.059 cal/g, °C (12).
Surface energy (0°K) (13) .. .. .. 640 ergs/cm²
Heat of fusion (27) .. .. 16,000 cal/mole
Heat of formation (28) (25–1,200°C) .. −259,500±2000 cal/mole
Free energy of formation (28) (25°C) .. −246,600 cal/mole
(727°C) .. .. −218,100 cal/mole
(1,227°C) .. .. −197,700 cal/mole
Entropy (14) (25°C) .. .. 18.6 cal/mole, °C
Thermal conductivity (see fig. 6) .. .. .. Table A1
Linear thermal expansion coefficient (see fig. 7) Table A2
Vapour pressure (10) (1,600–2,700°K) .. .. Table A3

$$\log p = 13.340 - \frac{3.7337\times10^4}{T} + \frac{3.6700\times10^6}{T^2} + \frac{2.4638\times10^9}{T^3}$$

Bend strengths (5, 13) (see fig. 9)
(Room temp.) .. .. 10,000–16,000 lb/in.²
(1,000°C) .. .. 16,000–18,000 lb/in.²
Crushing strength (5) (Room temp.) .. .. 150,000 lb/in.²
Youngs modulus (13) (Room temp.) .. 25–30×10⁶ lb/in.²
Compatibility
With coolants (6) .. .. Table A4
With metals (12, 6) .. .. Table A5

TABLE A1
Thermal Conductivity of UO_2
(Typical values corrected to zero porosity)

Temp. °C ..	200	400	600	800	1,000	1,200	1,400
K (cal/cm, sec, °C)	0.014	0.011	0.008	0.007	0.005	0.004	0.003

Over range 600–2,800°C the estimated average value is 0.003 cal/cm, sec, °C.

TABLE A2
Linear thermal expansion coefficient of UO_2 (5)

Temp. °C	27–400	400–800	800–1,260
Value (per °C) ..	9.2×10^{-6}	10.8×10^{-6}	12.9×10^{-6}

TABLE A3
Vapour pressure of UO_2 (10)

Temp. °C	1,326	1,702	2,126	2,363
p (mm Hg)	1.65×10^{-4}	6.67×10^{-3}	4.21×10^{-2}	9.66×10^{-1}

TABLE A4
Compatibility of UO_2 with coolants (6)

CO_2	Good at least to 900°C.
Water	Good at least to 300°C.
Hydrogen ..	Good to very high temperatures.
Liquid NaK ..	Variable behaviour in static tests.

TABLE A5
Compatibility of UO_2 with metals (6, 12)

Aluminium ..	Reaction occurs at 500°C but this is relatively slow with UO_2 particles >40μ.
Beryllium ..	Massive materials compatible to 600°C.
Stainless steel ..	Compatible to >600°C.
Niobium	Reacts at 1,000 °C.
Zirconium ..	Reacts with UO_2 at temperatures >800°C.
Nickel	Slow attack at 1,400°C.
Copper	Compatible in short term tests to their melting points.
Platinum	
Gold	

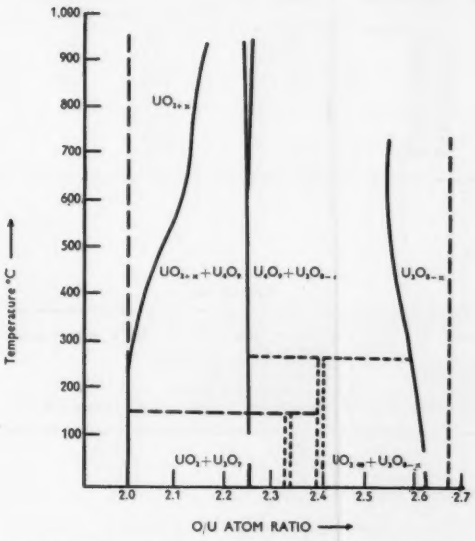
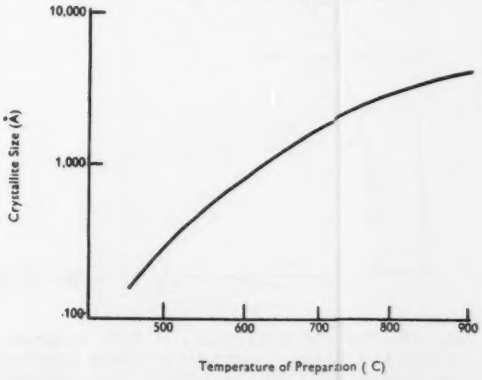


Fig. 1.—The uranium-oxygen system (2). Phase diagram of the uranium-oxygen system (2).

Fig. 2.—Variation of particle crystallite size with the temperature of reduction to UO_2 (3).



Bulk Density (g cm³)

Thermal Conductivity (cal/sec, cm, °C)

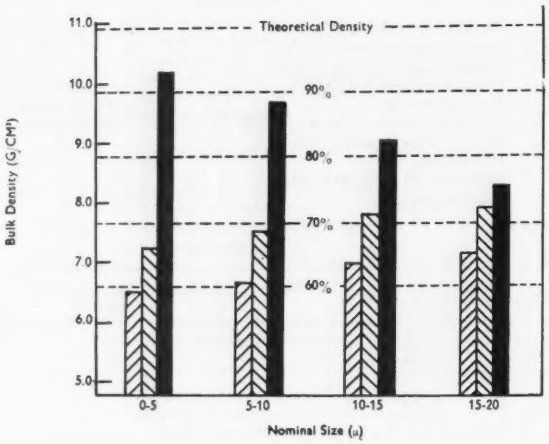


Fig. 3.—Variation in density with particle size of UO_2 powder at various fabrication stages (5).

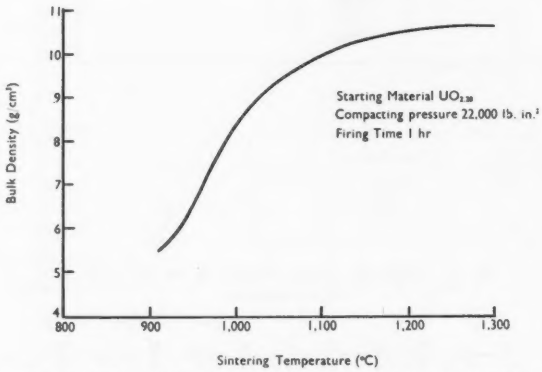


Fig. 4.—Effect of sintering temperature on the bulk density of non-stoichiometric UO_2 (6).

Fig. 6.—Variation of thermal conductivity of UO_2 with temperature.

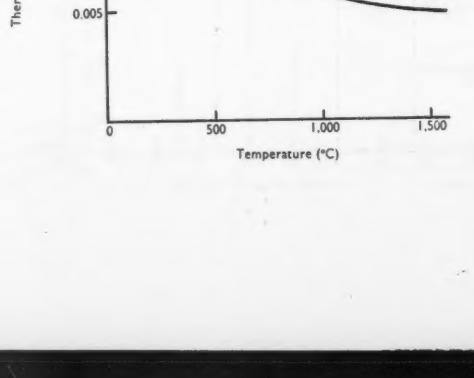

Valves corrected to zero porosity.
Kingery et al[33] (Density 8.0)
Hedge and Fieldhouse[35] (Density 8·19)
Thermal Conductivity (cal sec. cm. °C).
Temperature (°C)

Fig. 8.—(Right) Variation of the specific heat (Cp) of UO_2 with temperature (after Kelley) (9).

Fig. 9—(Right) The temperature dependence of bend strength (5) for specimens of fused UO_2 prepared from air-separated fractions (to nominal sizes quoted). As a binder addition, 1% of Carbowax 4,000 was used; the specimens were fired for ½ h in argon at 2,000°C.

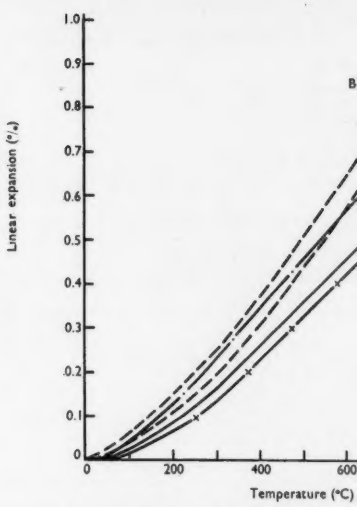
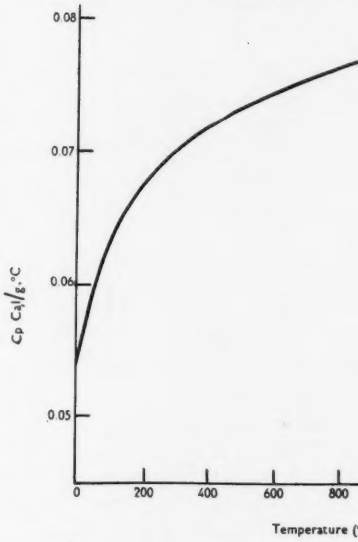
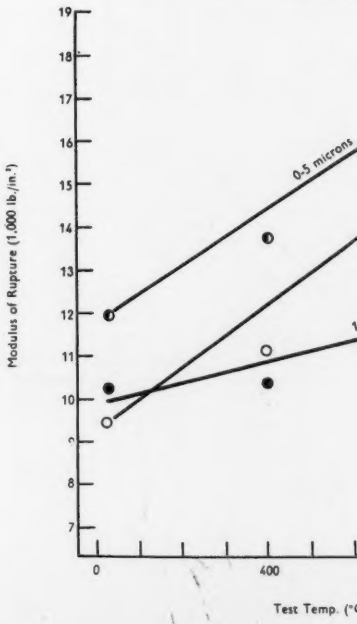
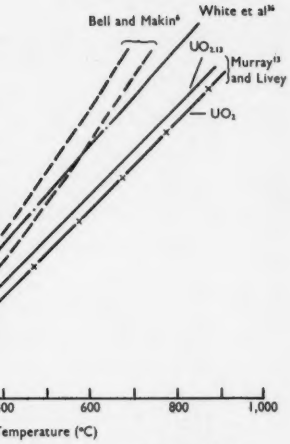


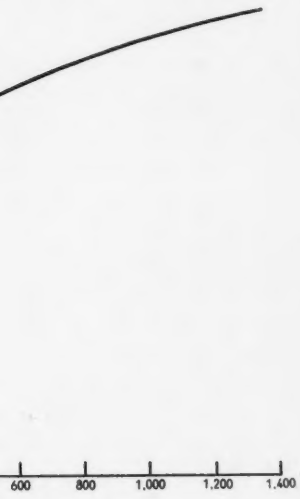
Fig. 7.—Variation of total thermal e with temperature.

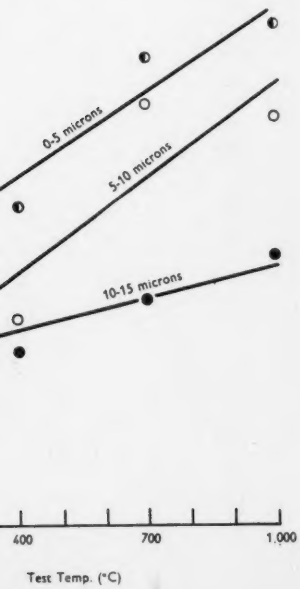






l thermal expansion of UO_2 mperature.





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B. URANIUM CARBIDE

Crystal structure .. .. Cubic, NaCl-type
Lattice parameter (25°C) 4.95Å
Theoretical density (25°C) .. .. 13.63 g/cm³
Uranium density (25°C) .. .. 12.97 g/cm³
Melting point (17) .. .. 2,350°C
Heat of formation (29) (25°C) .. .. 28,000 cal/mole
Thermal conductivity (6) (at 65°C) for zero porosity 0.04 cal/sec, cm, °C
Linear thermal expansion coefficient (16) (20—1,000°C) 10.5×10^{-6} in./in./°C
Bend strength (Modulus of rupture) (16)
Material with 12% porosity sintered at 2,100°C (Room temp. test) 11,000 lb/in.²
Hot extruded U+4.5 wt.% C (Room temp. test) 45,000 lb/in.²
(1,000°C) 23,000 lb/in.²
Hardness (16) UC sintered 2,100°C 750—800 V.P.N. (30 kg load)
U—UC cermets (see fig. 14)
Compatibility
With coolants (6,15) .. .. Table B1
With metals (6) .. .. Table B2

TABLE B1

CO_2	Oxidizes rapidly in CO_2 at 500°C, 8 atmospheres.
Water	UC decomposed at 80°C and above.
Hydrogen ..	Compatible to high temperatures if free from second phases.
Liquid NaK ..	Compatible with static NaK 800°C for 1 month.

TABLE B2

Niobium	Probably compatible at 500°C.
Stainless steel ..	Compatible to 1,000°C; reaction at 1,100°C (0.004 in. penetration after 6 days).
Titanium	Reaction at 1,100°C (0.005 in. penetration in 6 days); very marked attack at 1,200°C.

URANIUM SILICIDES

C. U_3Si

Crystal structure .. .. Tetragonal
Lattice parameters (25°C) .. .. .. 6.029; 8.696 Å
Theoretical density (25°C) .. .. .. 15.58 g/cm³
Uranium density (25°C) .. .. 14.99 g/cm³
Melting point .. .. 930°C (decomposes)
Thermal conductivity (19) (25°C) .. 0.036 cal/cm, sec, °C
Thermal expansion (20) .. .. Table C1
Hardness .. .. 240 V.P.N.
Mechanical strength (21) .. .. Table C2
Compatibility .. .. Table C3

TABLE C1

Temperature range (°C)	Mean coefficient of linear expansion ($\times 10^{-6}$ per degree C)
20–200	13.0
20–300	13.4
20–400	14.2
20–500	14.9
20–600	15.8
20–700	16.8
20–750	17.5

TABLE C2

Temperature (°C)	Yield strength (lb/in.²)		Ultimate or breaking strength (lb/in.²)	
	Tension	Compression	Tension	Compression
20	37,000	115,000	37,000	280,000
600		55,000		
700		18,000		
750		10,000		
850		4,000		

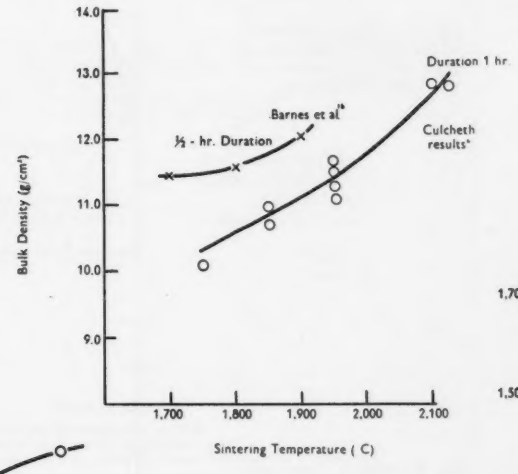

Fig. 13.—(Right) Effect of sintering temperature on the bulk density of UC.

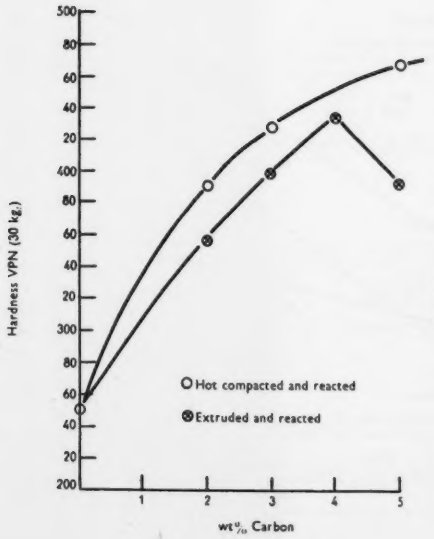

Fig. 14.—(Left) Variation of hardness with carbon content in U + UC cermets (16).

Fig. 16.—(Below) Phase diagram of the uranium-silicon system.

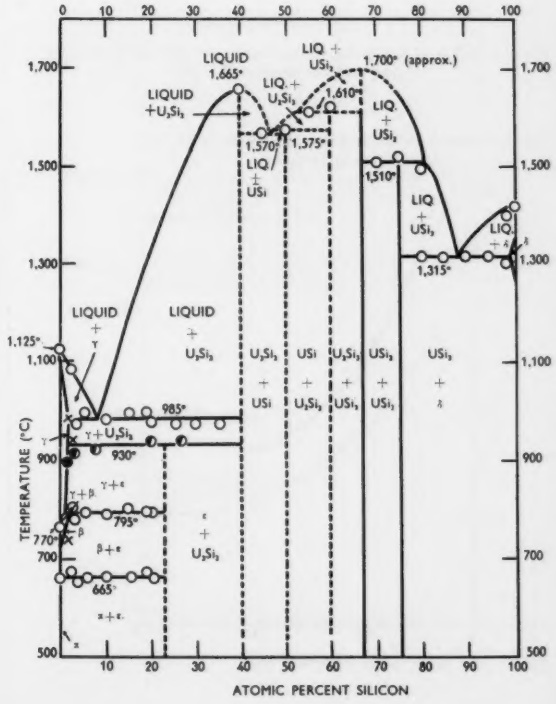

TABLE C3

Air (20)	Resistant at 100° and 200°C; some attack 300°C; rapid attack (20 wt% gain and disintegration in 7½ h) at 400°C.
Steam (20) ..	Slightly further attack than with water.
Water (30) ..	50 mg/cm²/month at 260°C. 1400 mg/cm²/month at 316°C.

D. U_3Si_2

Crystal structure .. .. Tetragonal
Lattice parameter (25°C) .. .. 7.33; 3.90 Å
Theoretical density (25°C) .. .. 12.20 g/cm³
Uranium density .. .. 11.31 g/cm³
Melting point .. .. 1,665°C
Thermal conductivity (65°C) (6) .. 0.035 cal/cm, sec, °C
Thermal expansion (20) .. .. Table D1
Compatibility (6, 20) .. .. Table D2

TABLE D1

Temperature range (°C)	Mean coefficient of linear thermal expansion (×10⁻⁶ per degree C)
20–200	15.5
20–300	15.3
20–400	15.2
20–500	15.3
20–600	15.2
20–700	15.1
20–800	15.0
20–900	14.7
20–950	14.6

TABLE D2

In air	1–19% wt. gain in 7½ h at 400°C with complete disintegration.
In CO_2	Behaviour similar to U metal.
Hydrogen ..	Probably incompatible.
Water	Not so resistant as U_3Si.
Liquid NaK ..	No attack after 1 week in static tests at 800°C.

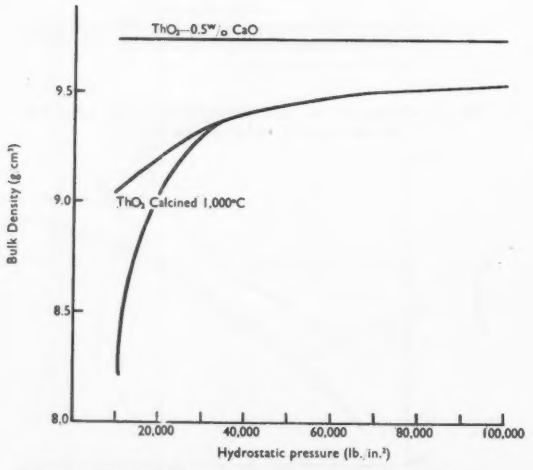

Fig. 17.—The final bulk density of ThO_2 specimens pressed at 5,000 lb/in.², repressed at various pressures and sintered for 1 hour at 1,800°C in an oxidizing atmosphere (after Lang & Knudson) (23).

E. THORIUM OXIDE

Crystal structure .. .. Cubic, CaF_2-type
Lattice parameter (25°C) 5.586
Theoretical density (25°C) .. .. 10.00 g/cm³
Melting point (11) .. .. 3,220±50°C
Thermal neutron absorption cross-section 0.165 cm⁻¹
Specific heat (12) (0–800°C) .. .. .. 0.058 cal/g °C
Heat of formation (31) .. $Th_{cryst} + O_{2\ gas} \rightarrow ThO_{2\ cryst}$
$\Delta H = -293{,}200$ cal/mole
Vapour pressure (32) .. log p (atms) $= -3.16\times10^{-4}/T + 7.20$
At 2,800°K $p = 10^{-4}$ atmospheres
Heat of vaporization (2,800°K) .. .. 14,500 cal/mole
Thermal conductivity (zero porosity) (33, 13) .. Table E1
Thermal expansion (see fig. 18)
Linear coefficient (34)
$\alpha_0 = 0.6216\times10^{-5} + 3.541\times10^{-9}\,T - 0.1125T^{-2}$ (T in °K)
Average value (24) 100–1,230°C, pure thoria 9.67×10^{-6}/°C
ThO_2 with 0.5 wt% CaO 9.93×10^{-6}/°C
Mechanical properties (23, 24) (see also Table 2 in text)
Bend strength (modulus at rupture) (Room temp.)
10,000–15,000 lb/in.²
1,000°C 10,000–15,000 lb/in.²
Crushing strength (Room temp.) .. .. 220,000 lb/in.²
Elastic modulus E (Room temp.) .. .. $20\text{–}35\times10^6$ lb/in.²
Value is dependent on sample but there is only a slight decrease with temperature in a particular case up to 900°C.
(Room temp.) .. .. 13.5×10^6 lb/in.²
900°C .. .. 11.7×10^6 lb/in.²
Knoop hardness, 500 g load 640
Compatibility (25)
Thoria is considered to be compatible with CO_2. It shows no weight change after 400 h in water at 315°C.

TABLE E1

Temperature (°C)	(cal/cm, sec, °C)
100	0.02–0.024
600	0.008–0.01
1,200	0.0076

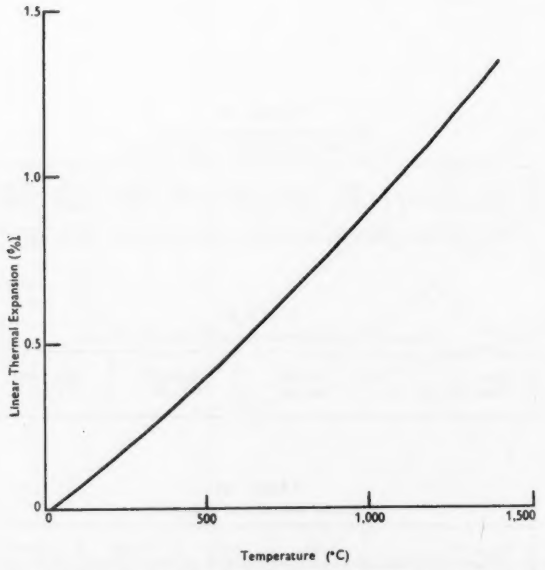

Fig. 18.—The variation of total linear thermal expansion with temperature for ThO_2—0.5 wt. % CaO compact (density 9.70 g/cm³ (23).

the vapour pressure, which reaches a measurable value well below the melting point. Weight losses and mass transfer to the furnace walls have been noticed during sintering at temperatures as low as 1400°C and these weight losses were higher in vacuum than under argon.[4, 12] The nature of the volatility is not yet clear and the volatile phase may be a higher oxide. The presence of foreign material such as BeO is reported to increase the volatility, which is also very dependent on the oxygen level.

Mechanical Properties

Because of its brittleness, measurements of the mechanical properties of UO_2 have largely been confined to bend tests. A sample of $UO_{2.13}$ with 9% porosity gave a modulus of rupture of 16,000 lb/in^2 at room temperature.[13] This modulus is dependent on fabrication variables, e.g. initial particle size (Fig. 9), presumably because of the effect of these variables on bulk density. Burdick and Parker[5] have shown that the modulus of rupture increases with increase of temperature, at least up to 1000°C when they obtained a value as high as 18,000 lb/in^2 with good reproducibility. Considerable scatter in results occurs, especially at low temperatures, as would be expected in brittle materials.

At higher temperature, some ductility may be possible, at least on non-stoichiometric material under slowly applied stress. Murray et al. reported[4] simple bend tests where a maximum fibre stress of 5,000 lb/in^2 was applied for two hours to a specimen 0.12 in. x 0.7 in. x 0.75 in. between supports. Permanent deflections at the centre of 0.001 in. at 800°C and 0.040 in. at 1000°C were measured using dense $UO_{2.14}$ specimens in an argon atmosphere. Under similar conditions in a hydrogen atmosphere or with stoichiometric specimens, no deflection was observed.

Other mechanical properties which have been measured are the elastic modulus[13] (about 25 x 10^6 lb/in^2) and the compressive strength. With stoichiometric specimens of length/dia. ratio 2 : 1, and density 10.1 g/cm^3, compression strengths of 140,000 lb/in^2 were achieved,[5] the specimens being completely powdered on failure. Somewhat higher strengths were obtained in specimens with lengths equal to their diameters.

Chemical Properties

A favourable feature of UO_2 is its relative inertness to most reactor coolants. It does not react with water at 300°C provided there is no appreciable pressure of oxygen above the water; no reaction would be expected with water vapour at higher temperatures.[6] With hydrogen, apart from reduction to the stoichiometric composition, there is no reaction up to very high temperatures. In wet and dry CO_2 the rate of oxidation of UO_2 in the temperature range 500-900°C is much slower than that of uranium at 500°C.[4] Little quantitative data exist on the compatibility with nitrogen, but sintering has been carried out[6] in this gas at 1450°C without harmful effects. In liquid sodium or NaK, variable behaviour has been reported. Thermodynamic data suggest that higher oxides should revert to UO_2 but no further reductions will occur; $UO_{2.14}$ specimens tested at Culcheth disintegrated completely to a sludge, but there is some evidence that high density stoichiometric material is compatible at 600°C.

With solid structural materials, reactions are frequently found with UO_2 powders which occur only slowly with high density massive UO_2. Such reactions occur[12] between UO_2 and aluminium at 500°C, and between UO_2 and carbon at 1800°C. Similarly there is no appreciable reaction between solid UO_2 and beryllium, even after long exposures at 600°C. Stainless steel is a suitable canning material to even higher temperatures.

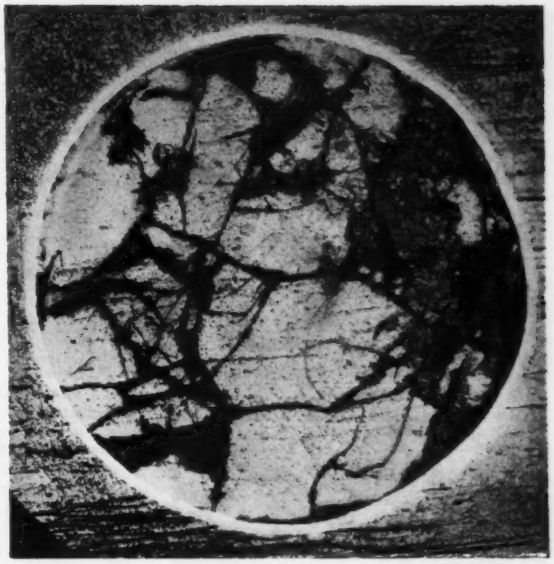

Fig. 10.—Thermal shock cracking in UO_2 in tight fitting stainless steel can. (6)

Effect of Reactor Conditions

Apart from any direct effect of irradiation, the presence of thermal gradients and thermal shock may be expected to produce cracking in a material as brittle and with such a poor thermal conductivity as UO_2. (Fig. 10.) Murray[13] has shown that quenching from as low as 200°C can reduce the room temperature bend strength of UO_2 by half. Additionally, cracking may result from any internal stresses produced by irradiation effects. Examination of irradiated specimens has shown[4] that cracking normally occurs roughly along a radial direction, but circumferential cracking is occasionally found. There is a difference between the behaviour of non-stoichiometric and stoichiometric oxides under irradiation in this respect. The former can sinter at appreciably lower temperatures in an inert atmosphere and the structure of irradiated non-stoichiometric material[4] strongly suggests that a series of radial cracks have formed at various times during irradiation, many of which have subsequently healed to a greater or less degree. The healed cracks appear as a line of bubbles, some of which appear distinctly as a fairly widely spread series of bridges across what may have been a crack, whereas in others the identity of lines of bubbles is almost completely lost.

Another effect of irradiation where the heat rating, size of fuel cross-section and heat transfer conditions are such as to produce high fuel temperatures is the formation of a hole down the axis of a fuel element as a result of central melting.

The high temperatures occurring in such an element can cause grain growth; Burdick and Parker[5] have shown that appreciable grain growth occurs in fine stoichiometric powder samples sintered at 2000°C (Fig. 11).

The growth of a central hole in a non-stoichiometric sample can result from a different mechanism to the melting mentioned above; a process of mass transfer by evaporation of oxygen-rich material, together with condensation and decomposition in cooler parts of the fuel element, has been described by Murray, Pugh and Williams.[4] A somewhat similar effect has been observed out of pile, when a non-stoichiometric specimen was subjected to a local hot spot produced by electron bombardment. (Fig. 12.)

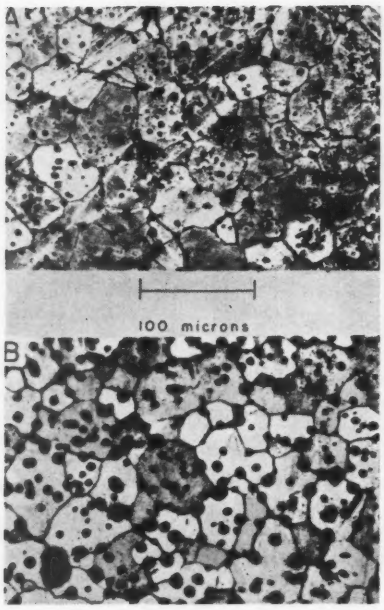

Fig. 11.—(Left) Photomicrographs of polished sections of specimens made from air-separated fractions of fused UO_2, sintered at 2000°C, etched 1 : 1 nitric acid (5).

(Upper) Specimen from 0.5μ particle size fraction; average grain size 48μ.

(Lower) Specimen from 5-10μ particle size fraction; average grain size 46μ.

Fig. 12.—(Right) Formation of central hole, nodules and cracks on the surface of a high density, non-stoichiometric UO_2 sample as a result of local surface heating by electron bombardment (6).

Finally, there is considerable evidence that $UO_{2.0}$ does not swell under irradiation, although the possibility of creep in non-stoichiometric material at temperatures as low as 800°C suggests that the behaviour of non-stoichiometric material may be different in this respect. There is much interest in how much of the fission product gases will be held on the lattice of UO_2 and what proportion will escape into the can; this will be dependent on the temperature of the fuel element, microstructure, density and composition. Greater releases may be expected in non-stoichiometric material because of the greater diffusion rates in the solid and the mass transfer effects referred to above.

Much remains to be done in the field of irradiation behaviour of uranium oxides but the growing interest in this material for advanced reactors may be expected to provide an incentive for this work.

URANIUM CARBIDE

Although three carbides of uranium have been reported, greatest interest has been shown in the mono-carbide UC. The dicarbide UC_2 is reported to be highly unstable[15] in the presence of water vapour, and rapidly reacts with nitrogen at 1100°C to form uranium nitride. A sesqui-carbide can only be formed in the presence of stress, and decomposes above 1800°C.

The monocarbide has a high uranium density and is of isotropic cubic structure without phase changes up to its melting point. It is thought to have a higher thermal conductivity than UO_2, but is not so chemically inert and it requires high fabrication temperatures to give high density material. Unlike the oxide, uranium monocarbide does not show any measurable composition range at temperatures below 1800°C.

Manufacture of UC

Uranium carbide powder can be prepared by the carbon reduction of UO_2 in vacuum at 1900°C, by the reaction of uranium powder with a gaseous hydrocarbon such as methane, or by the reaction of uranium with carbon at temperatures from about 1100°C.

When either of the first two methods are used, the resulting powder has to be cold-compacted and sintered. Hot pressing does not appear to be a suitable process[16] since high temperatures are required; if graphite dies are used there is a great risk of the formation of UC_2 with decreased resistance to chemical reaction.

The first operation in the cold-pressing route is the sizing of the powder which is dependent on the manufacturing conditions even within a particular process. As removed from the reaction vessel the powder arising from the gas-carburizing route[6] is in general finer than that from the solid reaction route; the latter requires crushing and grinding operations. UC powders, like those of uranium metal and other compounds, are markedly pyrophoric in air, and special precautions are necessary with particle sizes of less than 40μ.

Cold pressing by the usual techniques is followed by sintering under vacuum or in a non-oxidizing atmosphere at high temperatures, for example in a high-frequency furnace. The final density is dependent on the sintering temperature (Fig. 13) and for material with better than 95% theoretical density, sintering temperatures in excess of 2000°C are required; this leads to a material of relatively large grain size.

Since the theoretical density of a mixture of the right proportions of uranium and carbon powders (14.01 g/cm³) does not differ greatly from the theoretical density of the resulting UC (13.63 g/cm³) it is possible to use this process for preparing fuel element shapes. Elemental powders of suitable particle sizes are mixed and formed into the required shape by pressing, and then fired at 1000-1100°C for a sufficient time to complete the reaction to UC. The change of volume which occurs is greater than the 3% expected from the difference in theoretical densities and in order to get reasonable finished densities, a high density must be obtained in the pressing operations. For this reason hot pressing at temperatures of 700-800°C followed by reaction at 1100°C was recommended by Barnes and Murray.[16] They also demonstrated that the process could be used for the manufacture of U + UC cermets, which at higher carbon content consisted of uranium particles in a uranium carbide matrix. The highest density uranium carbide with no free uranium content so far made by this route is about 85% theoretical; it showed a much finer grain size than

material obtained by high temperature sintering. Uranium carbide can be wet-ground with diamond wheels and drilled by carbide tools or by an ultra-sonic technique.

Properties of UC

Because of the lesser interest in this material and because of the difficulties of obtaining reproducible material of high density, less is known of its properties than is the case with UO_2. The theoretical density (13.63) is one of the highest for uranium compounds, and the competitive thermal reaction cross-section of carbon is low. The melting point is about 2350°C,[17] values from 2250 to 2500°C having been quoted. An average value for the thermal expansion coefficient over the temperature range 20-1000°C is 10.5 x 10^{-6}in/in°C.

Information on thermal conductivity is limited to room temperature values, and very variable results are reported. Barnes[16] gives a value of 0.05 cal/sec cm°C for a high density compact, and Culcheth tests at 60°C have shown 0.032 for a density of 10.4g/cm³ (equivalent to 0.04 for a theoretically dense sample). Appreciably higher values have been quoted in American works.[18] The room temperature conductivity is thus somewhat better than that of UO_2 and approaches that of uranium metal (0.07 cal/cm sec°C).

Uranium carbide shows a relatively low electrical resistance (~5 x 10^{-5} ohm cm at 20°C)[6] which suggests a fairly high electronic contribution to thermal conductivity. The marked decrease with increase of temperature shown by UO_2 would not be expected for the carbide and preliminary measurements to 800°C have indicated only a gradual decrease.

As is the case with the oxide, the uranium carbide is very brittle, although of high strength, as indicated by its hardness (750-800 VPN).[16] The bend strength at room temperature varies greatly from one sample to another; for example, Barnes and Murray give values of ~12,000 lb/in² for UO sintered at 2100°C, and ~50,000 lb/in² for hot extruded U-4.5 wt%C material. The latter contained some free uranium which could be expected to reduce the brittleness and thus raise the modulus of rupture, but porosity and grain size may also be controlling factors. This material gave a value of 30,000 lb/in² in similar tests at about 1000°C. The monocarbide thus appears to be appreciably stronger than UO_2 under similar conditions. The same workers showed that the hardness of U-UC cermets increased progressively with carbon content (Fig. 14) and that such materials showed good creep strength even to the melting temperature of uranium.

Uranium carbide more readily reacts with some reactor coolants than does UO_2. It is decomposed by water at temperatures above 80°C with the evolution of hydrogen and gaseous hydrocarbons.[15] Uranium carbide oxidizes in CO_2, frequently forming a loose powder of UO_2 + free carbon; the oxidation behaviour is at least as bad as uranium metal at reactor operating temperatures.[6] On the other hand, tests at Culcheth Laboratories have shown UC to be compatible with hydrogen over a wide temperature range, providing that free uranium and UC_2 are absent. Static tests in liquid sodium[6] showed no change after one month at 600 and 800°C. At the reactor operating temperatures so far envisaged, UC appears to be compatible with such canning materials as stainless steel, beryllium and niobium but there is some evidence of reaction with stainless steel at higher temperatures, and marked reaction with titanium occurs at 1100°C. (Fig. 15.)

It may be concluded that UC shows a higher thermal conductivity, higher uranium density and possibly higher strength than UO_2, and may be suitable for use in hydrogen, liquid metal or nitrogen coolants; on the other hand its fabrication to high bulk densities is at present difficult and it shows a very much poorer resistance to oxidation by CO_2 at reactor operating temperatures than does uranium oxide.

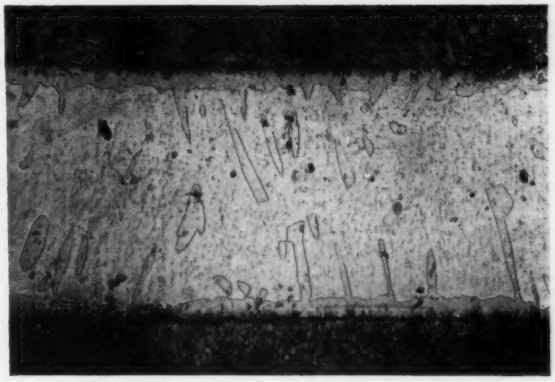

Fig. 15.—Interaction between UC and titanium after six days at 1100°C. Titanium is in centre, with reaction layer (probably TiC) 0.005 in. thick. (6)

URANIUM SILICIDES

The uranium-silicon system (Fig. 16) contains several compounds with a range of melting points and properties. The compound of highest uranium content U_3Si (frequently known as the epsilon phase) has been favoured for water-cooled reactors because of its reported high corrosion resistance.

However, this material which is relatively soft and somewhat ductile, decomposes by a peritectoid reaction at a low temperature (930°C) and can be considered rather as an alloy of uranium metal than as a ceramic fuel. The higher silicon compounds are more refractory than this, but even so show appreciably lower melting points (e.g. U_3Si_2 1665°C) than the oxides and carbides. For this reason it has been suggested that the compounds will be easier to fabricate than the carbide; in density and other properties U_3Si_2 is thought to show more resemblance to UC than to the oxide.

Preparation of U_3Si

Each of the compounds can be prepared by melting together mixed elemental powders in the correct composition. The molten silicides are very reactive and so to avoid excessive crucible attack with resultant contamination, short melting periods are necessary and arc melting in water-cooled moulds has been used. As a result the as-cast materials are frequently heterogeneous, and annealing treatments are usually carried out at temperatures just below the phase transformation temperature of the respective compound. The compound U_3Si can be shaped by techniques usual for a metal; for example it has been coextruded with other metals in the temperature range 750°C-800°C. With the other silicides it is usual to grind them to powder and then process them into the required shapes by the techniques of powder metallurgy. The silicide powders all tend to be pyrophoric in air and care must be taken during the grinding, sizing and handling operations. Sintering can be done in a pure argon atmosphere or under high vacuum; temperatures around 1400°C are typical. A typical bulk density for U_3Si_2 shapes, compacted at 25 ton/in² and sintered under vacuum for two hours at 1400°C is about 10.8 g/cm³, about 95% of the theoretical density.[6]

Properties

Considering first the epsilon phase U_3Si, this material has a uranium density higher than UC but decomposes at the

much lower temperature of 930°C. Only low temperature measurements of thermal conductivity are available, the values (0.036 cal/cm sec°C at 25° C)[19] being similar to those for uranium carbide. The thermal expansion coefficient for U_3Si is the highest for all the ceramic materials discussed in this paper, the average value[20] from 20 to 700°C being 16.8 x 10^{-6} per °C.

This compound shows some ductility under mechanical deformation. Because of this its breaking strength in compression tests (280,000 lb/in²) is somewhat higher than that found for UO_2 (140,000 lb./in²) even though it is appreciably softer (about 240 V.P.N.). It maintains a reasonable compressive strength up to 750°C. For example, at 600°C a compressive yield strength of 55,000 lb/in² is quoted for U_3Si, as compared with a tensile yield strength for uranium metal of only 9,000 to 25,000 lb/in² at this temperature.

U_3Si is more resistant to water and steam corrosion than uranium metal but for this purpose it is essential that the composition and heat treatment of the alloy is such as to give a single phase structure (the epsilon phase only exists over a narrow range of compositions). This difficulty of ensuring freedom from other phases before and during irradiation may make this an unsuitable material for use with hydrogen coolants. In oxidizing conditions its behaviour is similar to that of uranium metal; it is reported that it resists oxidation in air at 100 and 200°C, but not at 300°C, and at 400°C attack is rapid. Irradiation tests on U_3Si have been reported by Epremian[22], who showed that extruded samples irradiated to only 0.06% burnup at 200°C showed a 4% decrease in density with large increases in hardness and electrical resistivity. The rate of corrosion in water at 350°C was apparently unchanged by irradiation but the mode of corrosion changed to spalling. Irradiation experiments on cast and homogenized samples of U_3Si were somewhat more encouraging than on the extruded material; after 0.63% burn-up at a temperature below 500°C it showed about 4% increase in volume. With 0.8% burn-up at 700°C there was a 3% increase in length with a 30% increase in diameter, associated with the formation of central hole.

U_3Si_2 is the next silicide in order of uranium content, its theoretical density (12.2 g/cm³) being intermediate between those of UO_2 and UC. It shows no phase changes to its melting point (1665°C) provided it consists of only the one phase. Excess silicon gives a eutectic which melts at 1570°C. Like other uranium silicides its thermal expansion is rather high (15 x 10^{-6} per degree C)[20] and its thermal conductivity at 65°C is about 0.035 cal/cm sec°C.[6] There is little information on its mechanical properties, but it is very brittle; its oxidation behaviour is similar to that of uranium metal and it shows less resistance than U_3Si to corrosion by water. No results of irradiation experiments have been reported.

THORIUM COMPOUNDS

As in the case of uranium, the compounds of greatest interest with thorium are the carbides and oxide. Thorium forms two carbides, the monocarbide ThC and the dicarbide ThC_2. The former is of the cubic NaCl-type structure ($\alpha 0 = 5.34$Å) similar to UC and its melting temperature is about 2625°C. Unlike the uranium compound it does show a range of composition at room temperature from 3.8 w/o C to 4.9 w/o C. The dicarbide is of monoclinic structure and melts about 2655°C. Little has been published on the properties of these carbides and the only thorium compound which has been studied in detail is the oxide thoria ThO_2.

In many respects thoria is similar to urania; it has a similar lattice structure (CaF_2 type) and the two compounds form a series of solid solutions. However, thoria is the only stable oxide of thorium and therefore unlike UO_2 it is not oxidized in air. It shows a somewhat higher melting point (3200°C) than uranium, but the other physical properties are somewhat similar.

Fabrication of ThO_2

Thoria shapes can be made by slip casting followed by sintering, by cold compacting and sintering or by hot-

Les Combustibles Céramiques pour les Réacteurs Nucléaires

Le remplacement de l'uranium métallique par les combustibles céramiques donne une plus grande stabilité dimensionnelle des éléments combustibles sous l'irradiation, permet l'obtention de températures de combustible plus élevées et donne une plus grande résistance à l'attaque par le matériau de canning. Naturellement, certains inconvénients sont entraînés, tels que le besoin d'enrichissement, la faiblesse mécanique des matériaux, la prévision d'un support supplémentaire pour ces derniers, et certaines difficultés de fabrication. Cet article traite des propriétés de l'oxyde d'uranium. Les carbures et siliciures d'uranium et les carbures et oxyde de thorium sont d'autres matériaux qui présentent un intérêt et qui seront l'objet d'un examen dans un prochain numéro.

Il reste encore beaucoup à faire, particulièrement dans le domaine des essais d'irradiation.

Keramische Brennstoffe für Kernreaktoren

Einsetzen von keramischen Kernbrennstoffen anstelle von metallischem Uran gibt dem Brennstoffelement unter Bestrahlung grössere dimensionale Stabilität, ermöglicht Verwendung höherer Brennstofftemperaturen und führt zu grösserer Widerstandsfähigkeit gegen Angriff durch das Hülsenmaterial. Naturgemäss sind auch gewisse Nachteile damit verbunden, wie etwa die Notwendigkeit der Anreicherung, eine mechanische Schwäche des Materials, die zusätzliche Abstützung erfordert, sowie gewisse Fabrikationsschwierigkeiten. Dieser Artikel befasst sich mit den Eigenschaften von Uranoxyd. Die Urankarbide und Uransilizide, sowie Thoriumkarbide, sind andere interessante Stoffe, die in einem späteren Artikel behandelt werden sollen.

Es ist noch viel Forschungsarbeit zu leisten, insbesondere auf dem Gebiet der Prüfung der Einwirkung von Bestrahlung.

Combustibles Cerámicos para Reactores Nucleares

La substitución de combustibles cerámicos en lugar de uranio metálico ofrece mayor estabilidad dimensional de elementos de combustible bajo irradiación, permite temperaturas más elevadas de combustible y ofrece mayor resistencia a ataque por el material de envasado. Naturalmente, a la par con estas ventajas existen ciertas desventajas, tales como la necesidad de enriquecimiento, la debilidad mecánica de los materiales que hace que sea necesario tener soporte adicional, y ciertas dificultades de fabricación. Este artículo trata de las propiedades del óxido uránico. Los carburos y silicidios uránicos y los carburos y óxido de torio son otros materiales interesantes, y se tratará de ellos en un artículo futuro.

Todavía queda mucho trabajo que hacer, particularmente en el campo del ensayado de irradiación.

TABLE 2

Effect of CaO additions on the mechanical properties of ThO_2 (after Curtis and Johnson) (24)

Addition wt%	Firing temp °C (2 hr period)	Density g/cm³	Porosity (apparent) %	Modulus of elasticity lb/in.²	Modulus of rupture lb/in.²	Crushing strength lb/in.²
None	1,800	8.02	17.6	19.6×10^6	13×10^4	21.0×10^4
None	1,900	9.14	1.8	—	—	—
0.5 CaO	1,800	9.65	0	20.9×10^6	19×10^3	35.5×10^4
1.0 CaO	1,800	9.5	0	33.9×10^6	20×10^3	40.0×10^4
3.0 CaO	1,800	9.0	0	43.6×10^6	26×10^3	—

pressing. As with other ceramics the ease of fabrication is dependent on the powder material and a small particle size is advantageous. The powder can be made by thermal decomposition of such compounds as the oxalate, and the calcining temperature used affects the fabrication behaviour. Sintering appears to occur at a temperature about 200°C lower than with stoichiometric UO_2.

In the slip casting process high purity thoria is ground to give 95% of the particles below 10 microns in size; this powder is then leached, washed and adjusted to a pH of from 1.0 to 3.5.[13] The bulk density of dried slip castings is high (about 30% porosity) and they can be fired at 1600-1900°C directly, provided the heating rate is slow. Alternatively a pre-sinter at 1300-1400°C gives sufficient strength to permit fairly rapid heating to a final sintering temperature. Sintering of thin sections to over 9.6 g/cm³ is accomplished rapidly at temperatures above 1750°C. Solid sections, such as may be made by cold compacting, sinter rather less readily but high densities can be achieved with sintering temperatures above 1750°C using suitably graded powder.

Several workers have shown that small (~0.5 wt%) additions of lime facilitate sintering. For example Lang and Knudsen[23] obtained a bulk density with pure thoria of 9.5 g/cm³ by the sintering at 1800°C of compacts hydrostatically pressed at 100,000 lb/in². Under similar conditions 99.5% ThO_2 + 0.5 wt% CaO gave 9.73 g/cm³. The magnitude of the effect depended on pressing pressure (Fig. 17). Curtis and Johnson[24] found an even bigger difference obtaining a density of 8.02 g/cm³ for pure thoria sintered at 1800°C for 1 hr. compared with 9.65 g/cm³ for thoria containing 0.5 wt% CaO. Unlike UO_2, the densification of pure thoria is not dependent on furnace atmosphere. When CaO additions are made however, a reducing atmosphere appears to be unfavourable. Hot-pressing of thoria at 1800°C to a bulk density 9.6 g/cm³ has been demonstrated by Murray and Livey;[13] considerable grain growth, especially at the surface, was reported for specimens pressed at 1850°C or above. In sintering experiments it was claimed that CaO additions reduced the grain growth which occurred at 1800°C, for example during the sintering process. As with other ceramics, machining is normally done by grinding, using silicon carbide or diamond wheels. Care is needed to avoid chipping the edges of the shapes.

Properties of ThO_2

The thermal conductivity of thoria is similar to that of urania. Values of about 0.02 cal/cm sec°C at 100°C are quoted, reducing to about 0.008 at 600°C.

The thermal expansion coefficient is dependent on temperature (Fig. 18), a typical average value for the temperature range from room temperature to 1200°C being 9.5 x 10^{-6} per °C. Thoria is a brittle material and its bend strength depends on density and specimen size. Values of 12,000 to 15,000 lb/in² at room temperature are typical and there is little change on increasing the test temperature to 1000°C. Crushing strengths in excess of 200,000 lb/in² have been reported[23] with a Knoop room temperature hardness number of 640 (500 g load). There is evidence that additions of CaO alter the physical and mechanical properties, and this effect is not simply due to differences in density.[24] Slightly higher thermal expansions and markedly higher elastic modulus and strength values were reported to result from lime additions (Table 2). Apart from its greater resistance to low temperature oxidation thoria shows similar chemical properties to UO_2. It shows no change of weight after exposure to water at 315°C for 400 hrs.[25] It can be dissolved in acid media such as nitric containing small amounts of hydrofluoric acid solution. There is little reported information on its irradiation behaviour, but Johnson states[37] that it is stable to dimensional change on irradiation.

Conclusions

Although the technology of some ceramic fuels is well advanced, much remains to be done, especially in the fields of property determination and irradiation testing. In particular little is known of the effects of material variables on irradiation behaviour. The mode of preparation, grain size, composition and effect of deliberate alloying additions may all be most important in controlling the permissible burn-up of a particular fuel element design. Another field of interest is the investigation of other compounds, in particular the oxides and carbides of the plutonium system. A big incentive to such work is given by the growing demand for reactors producing power at a lower cost, which could result from the higher coolant temperatures, higher fuel ratings and higher burn-ups which may be possible with ceramic fuels.

Acknowledgment

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Power Reactors in Canada

NPD and CANDU Studies

This article describes the activities of the Nuclear Power Branch of the Canadian Authority. A 20 MW unit is under construction and a study has been made of a 200 MW unit.

CANADA, as is generally known, was among the pioneers in the nuclear field, her zero-energy heavy water pile ZEEP being the first nuclear reactor in the world outside the U.S., while NRX went into operation as long ago as 1947. Although a considerable amount of effort was devoted by Atomic Energy of Canada Ltd. to research on the fundamentals of power reactors, it was not until early 1954 that the Nuclear Power Branch was set up at Chalk River to study reactor design for economic electricity production.

The first major task of this group was the conceptual design of a pilot unit, known as NPD (Nuclear Power Demonstration) with a thermal power of 80 MW and a net electrical output of 20 MW. In 1955 an agreement was reached for the construction of this reactor, under which A.E.C.L. would be responsible for the development work, the Canadian G.E. would carry out detail design and construction, and the steam plant would be supplied and the station operated by Ontario Hydro, who made available a site close to its hydro-electric plant at Des Joachims, on the Ottawa River.

In September, 1955, the Nuclear Power Branch commenced a detailed study of a full-scale power reactor with the result that early in 1957 the construction of NPD was held up and the design modified in accordance with some of the features of the large reactor that the study had evolved. The redesigned pilot unit, now officially known as NPD-2, is expected to go into operation in 1961. The general arrangement of the plant is shown in the cut-away drawing (Fig. 1).

The CANDU Study

The large power reactor covered by the study is known as CANDU (Canadian Deuterium-Uranium Reactor). It would have an output of 200 MW, and is considered to be practicable in the following circumstances:—

(1) Absence of low-cost undeveloped hydro resources or cheap fossil fuel in the area.
(2) Growth of electricity demand large enough to permit base-load operation and with sufficient system reserve to permit of shutting down from time to time.
(3) Finance rates comparable with public utilities in Canada.

The reactor covered by the study is a heavy water moderated unit fuelled with natural uranium in oxide form. There are, however, a number of ideas which can be classified as "advanced" and one or two departures from conventional thinking that give to the design an unusual interest.

TABLE 1. CANDU Design Particulars
(British equivalents of metric sizes are approximate only)

Thermal output	794 MW
Electrical output, gross	208.4 MW
net	200 MW
Core	
Diameter (active)	552 cm (18 ft 1½ in.)
(over reflector)	614 cm (20 ft 2 in.)
Length (active)	507 cm (16 ft 7½ in.)
(over reflector)	568 cm (18 ft 7½ in.)
Fuel channels	252
Lattice pitch (square)	30.8 cm (12.2 in.)
Volume of materials in cm³ per cm of channel length	
Fuel	50
Canning	10.5
Coolant	40
Element supports	1.4
Pressure tube	22.5
Calandria tube	6.3
Helium	12.1
Flux at core centre, max.	2.24×10^{14} n/cm², sec
average	1.7×10^{14} n/cm², sec
Lattice Parameters	
π	1.020
η_i	1.187
p	0.9176
f	0.9350
k	1.039
L^2	244 cm²
L_s^2	140 cm²
H^2	1.02 m⁻²
Fast leakage	0.014
Thermal leakage	0.025
Initial conversion factor	0.77
Irradiation of fuel	7150 MWD/t oxide 8150 MWD/t uranium
Content of irradiated fuel in g/kg of oxide	
U^{235}	1.49
U^{236}	0.75
Pu^{239}	2.76
Pu^{240}	0.89
Pu^{241}	0.25
Fission products from U^{235}	4.09
Fission products from U^{238}	0.25
Fission products from Pu	3.36
Moderator	Heavy Water
Temperature, inlet	71°C (160°F)
Temperature, outlet	88°C (190°F)
average	80°C (176°F)
Weight of heavy water in core	112 tonnes
in cooling circuit	8 tonnes
Fuel Element	
Dia of rods for 61-rod element	0.9 cm—1.27 cm
for 31-rod elements	1.49 cm
Thickness of Zircaloy sheath	0.051 cm
No. of elements per channel	18
total	4500
Peak temperature of fuel centre	2200°C (4000°F)
Peak temperature of sheath	282°C (540°F)
Total fuel investment	70 tonnes
Pressure tube int. dia	11.36 cm (4½ in.)
Wall thickness	0.6 cm (¼ in.)
Helium-filled space	0.3 cm (⅛ in.)
Calandria tube wall thickness	0.15 cm (1/16 in.)
Coolant	
Type	Heavy water
Total investment	49 tonnes
Mass flow	190 m³/min (25×10^6 lb/h)
No. of pumps	8
Pump rating	600 h.p.
Flow	27 m³/min (6000 gal/min)
Temperature inlet	221°C (430°F)
outlet	274°C (525°F)
Working pressure	1000 p.s.i.
No. of heat exchangers	8
Pressurizing tank diameter	10 ft
Heat Exchangers	
Type	U-tube
No. of tubes	3750
Dia	1.27 cm (0.5 in.)
Length	10 m (31 ft)
Surface area	1360 m² (14,600 sq. ft)
Steaming rate	344,000 lb/h
Steam temperature	215°C (419°F)
Steam pressure	Saturation (approx 305 p.s.i.a.)
Steam drum length	40 ft
dia	5 ft

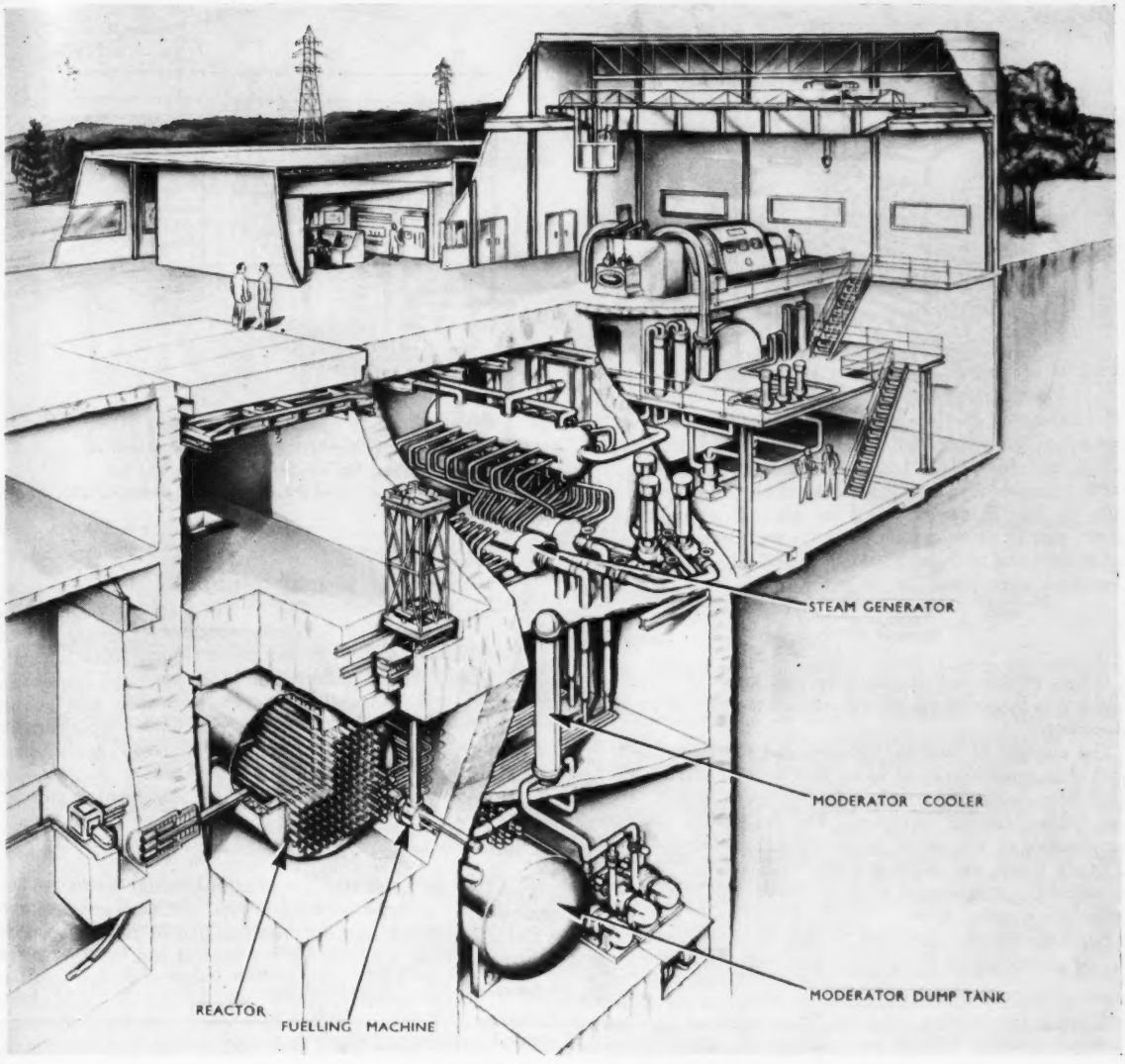


Fig. 1.—Cut-away drawing of NPD.

The output capacity of 200 MW was chosen on economic grounds. Preliminary studies with a target of 5 mills/kWh indicated that a 100 MW station could not be successful, while a 150 MW plant would be marginal, its success depending on whether a low-cost alloy could be used for fuel canning. At 200 MW it was considered that the target could be met even using Zircaloy 2. Higher ratings, although possibly more economical, would require a larger capital outlay than that considered justifiable for a first plant.

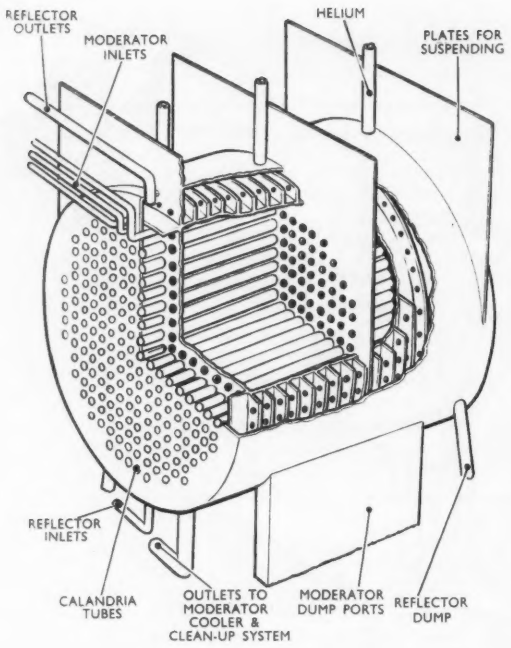
The general design envisaged uses pressurized heavy water cooling, but with pressure tubes instead of a main pressure vessel. These tubes, containing the fuel elements, are surrounded by a calandria vessel (Fig. 2), which contains the heavy water moderator and the reflector, which may be either light or heavy water. The moderator is separately cooled and is not under pressure.

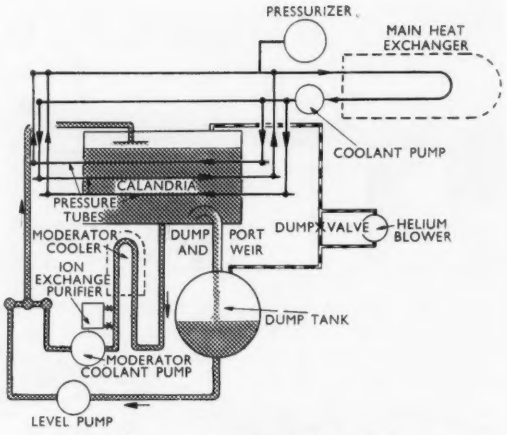
Control of the reactor is by adjusting the level of the moderator; there are no control rods or operating mechanisms. Heavy water circulated through the pressure tubes as coolant is itself cooled in a number of heat exchangers. A considerably simplified flow diagram is shown in Fig. 3.

Fuel

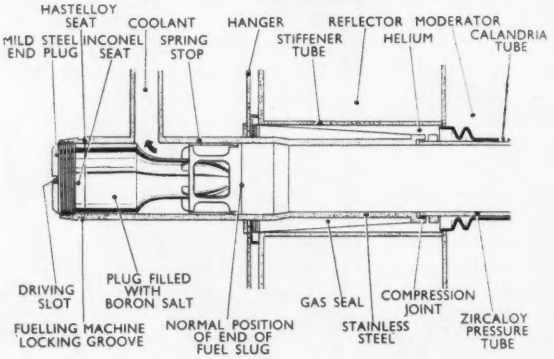
One of the underlying philosophies of the design is that there is more to be gained by increasing burn-up than by increasing the rather low thermal efficiency by improvement in steam conditions. Oxide was chosen, on account of its greater dimensional stability than uranium metal, and its comparative inertness to hot water in case of a can failure. The irradiation planned is (for nat. U) the high figure of 8,100 MWD/tonne of contained uranium, this being the limit set by fission product poisoning.

No enrichment whatever is planned. The use of plutonium produced in the reactor itself would involve fuel processing and refabrication plant, and it is felt that this could not be economic until very large supplies of spent fuel are available. Enrichment with U^{235} was studied, and it was considered that there might be a case for enrichment





(Left) Fig. 2.—Arrangement of the calandria.
(Above) Fig. 3.—Simplified flow diagram.
(Below) Fig. 4.—End arrangements of pressure tube.



if it was certain that the burn-up time could be doubled; as this was by no means certain, enrichment would be more expensive.

The amount of fuel per channel and the power density were chosen arbitrarily at $7\frac{1}{4}$ sq. in. (50 cm^2) and 5.8 kW/lb (12.8 W/g) respectively. Cost studies taken at 40% above and below showed increases. The maximum allowable temperature of the oxide, based on irradiation experience at Chalk River, was taken as 4,000°F (2,200°C). This was considered conservative, as it is about 1,000°F (550°C) below the melting point.

For heat transfer purposes, it was decided that a total wetted perimeter of 85 in. (215 cm) was necessary using solid cylinders; flat bars or tubes in uranium oxide are not considered to have yet been proved practical in operation. The original fuel element proposed had 61 rods, varying in diameter from 1.27 cm for the central rod, to 0.9 cm for

Les Réacteurs d'Energie au Canada

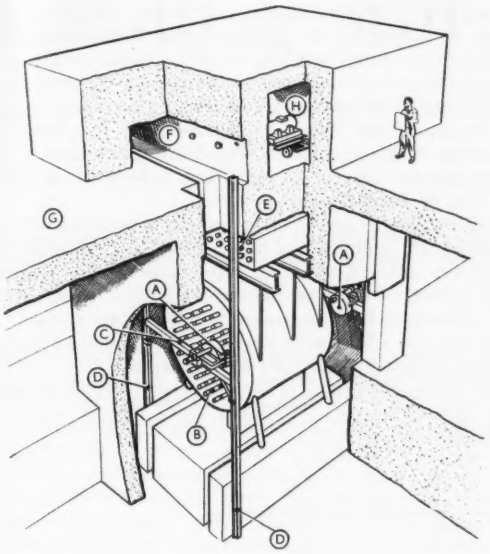
La conception d'un réacteur d'énergie à eau lourde de 20 MW connu sous les initiales NPD (Nuclear Power Demonstration) fut entreprise en 1954 par la Section de l'Energie Nucléaire de l'A.E.C.L. Dès 1955, l'équipe s'occupait de l'étude d'un réacteur d'énergie de grandeur naturelle et, en 1957, lorsque la construction du NPD était déjà en train sur un site dans les environs de Des Joachims sur la Rivière Ottawa, il fut décidé d'apporter des changements radicaux, basés sur l'étude du grand réacteur d'énergie. Cet article donne de brefs détails du réacteur pilote NPD tel qu'il est remanié actuellement, et que l'on s'attend à voir entrer en fonctionnement pour 1961, et du grand réacteur d'énergie, dénommé maintenant CANDU, conçu pour un rendement net de 200 MW. Les deux modèles emploient de l'eau lourde comme modérateur dans un groupe de calandres entourant des tubes à pression contenant le combustible et le réfrigérant eau lourde. On envisage le changement de combustible en charge.

Leistungsreaktoren in Kanada

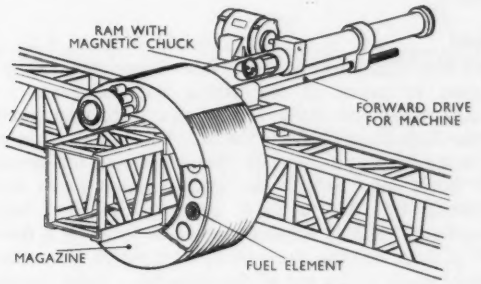
Die Konstruktionsarbeiten für den Schwerwasserreaktor NPD (Nuclear Power Demonstration) wurden im Jahre 1954 von der Abteilung für Kernkraft der AECL aufgenommen. Im Jahre 1955 begann die Gruppe mit den Vorarbeiten für Bau eines grossen Leistungsreaktors, und im Jahre 1957, als der NPD–Reaktor auf dem Gelände bei Des Joachims am Ottawa–Fluss bereits im Bau war, entschloss man sich auf Grund der für den grossen Leistungsreaktor durchgeführten Untersuchungen zu radikalen Konstruktionsänderungen. Dieser Artikel bringt Einzelheiten des NPD–Versuchsreaktors (Inbetriebnahme wahrscheinlich 1961) in seiner jetzigen Form, und des grossen Leistungsreaktors, CANDU benannt, der für eine Nutzleistung von 200 MW ausgelegt ist. In beiden Reaktoren wird schweres Wasser als Moderator in einem Röhrenheizkörper aus Aluminium benutzt, der die Druckröhren mit Spaltstoff und Schwerwasserkühlmittel enthält. Der Brennstoffwechsel soll unter Last vorgenommen werden.

Reactores de Energia Nuclear en el Canada

El diseño de un reactor de energía nuclear a base de "agua pesada" de 20 MW, conocido como el "NPD" (Nuclear Power Demonstration—Demonstración de Energía Nuclear) se comenzó a evolucionar en 1954 por el "Nuclear Power Branch"—(Ramo de Energía Nuclear)—de A.E.C.L. Ya por 1955, el equipo seleccionado estaba elaborando el estudio de un reactor de energía nuclear de tamaño completo y, en 1957, cuando ya había comenzado la construcción del "NPD" en un sitio cerca de Des Joachims en el Rio Ottawa, se decidió que debieran hacerse cambios radicales, basados en el estudio del reactor de energía grande. Este artículo ofrece breves detalles del reactor piloto "NPD" conforme ha quedado ahora diseñado de nuevo, que se espera esté en funcionamiento en 1961, y del reactor de energía grande, el que ahora se ha denominado "CANDU," y que ha sido diseñado para dar un rendimiento neto de 200 MW. Ambos diseños emplean "agua pesada" como moderador, en una calandria de aluminio encerrando tubos de presión conteniendo el combustible y el agua pesada de enfriamiento. Se prevee cambio de combustible en carga.



(Left) Fig. 5.—Fuel handling arrangements.



(Below) Fig. 6.—Enlarged view of fuel machine.

the outermost ring. Present thinking favours a 31-rod design, all rods being 1.49 cm in diameter. It is, of course, possible that a 19-rod element might be used.

The sheath temperature for the canning material (Zircaloy 2) has been set at a maximum of 540°F (282°C). Raising the temperature would improve the thermal efficiency, but would, of course, necessitate operation at higher pressures and, therefore, involve thicker pressure tubes, which would, in turn, lead to greater neutron absorption and, thus, to shorter burn-up.

Coolant

Heavy water pressurized to 1,000 p.s.i. was selected as the coolant. Natural water was considered but was turned down after a comparatively short study. The fixed charges on heavy water are estimated at about 0.15 mills/kWh. A net loss of 1 lb/h would double this, and give a total of about 15% of the fuelling cost. Natural water would cause neutron losses that would add more than this, so that heavy water is economic providing losses can be kept down to about 1 lb/h (6 lb/h would add 1 mill/kWh to the cost, thus making the scheme uneconomic in Canada). Other arguments against natural water are:—

1. Formation of bubbles and voids in the coolant changes reactivity far more than heavy water.
2. Amount of coolant in each channel would have to be reduced to the minimum, leading to high temperature rise.
3. Smaller lattice pitch would be required, causing mechanical difficulties.
4. The containment problem is no easier.

Inlet and outlet temperatures of the coolant are 430°F (221°C) and 525°F (274°C) respectively. Pressurization to 1,000 p.s.i. is carried out by a vessel 10 ft dia with a helium atmosphere.

Pressure Tubes

The pressure tubes have been designed in Zircaloy 2 and have an inside diameter of 4.48 in. (11.36 cm) with a wall thickness of 0.236 in. (6 mm) giving a maximum working stress of 10,000 p.s.i. (700 kg/cm^2) and a safety factor, on yield, of 1.8. The pressure tube is surrounded by an annular space between itself and the calandria tube, which is filled with helium under pressure acting as a heat insulation layer to restrict heating of the moderator.

The actual design of the tube ends is comparatively complicated since the connections for the incoming and outgoing coolant are arranged at the side, so as to leave the tube ends free for fuel changing. The arrangement is shown in Fig. 4, which details the compression-type joints to stainless-steel fittings that provide fuel and coolant ports; these are provided with plugs filled with a boron salt to cut down stray neutrons.

Calandria

The calandria is a double-walled aluminium cylinder, 20 ft 2¼ in. diameter and 18 ft 8 in. long overall. There is a space of about 1 ft all round between the outer and inner cylinders, secured with perforated aluminium stiffening rings at the sides and tubes at the ends; this space forms the reflector which, as can be seen from Fig. 2, has inlet and outlet arrangements which are not only separate from the moderator, but from each other, so that heavy water could be used for the reflector surrounding the core and light water at the ends. The material for the reflector has not yet been finally decided. It was originally considered that, since the neutron leakage was low, there would be little justification for the extra capital investment, but recent studies at Chalk River have shown that the use of a heavy water reflector gives much better flux flattening, thus equalizing, to some extent, the heat transfer rate across the core. It would also reduce the number of fuel channels by some 20%. There are 252 channels in the present design.

The calandria tubes which surround the pressure tubes and their helium blanket, are of aluminium; they are provided with expansion bellows at the ends, this arrangement can be seen in Fig. 4.

Fuel Handling

The fuel elements are comparatively short (eight to the channel) and it is intended that on-load charging and discharging shall be carried out, charging at one end of a tube and discharging at the other, so that each operation takes place at both ends of the reactor. Figs. 5 and 6 give an idea of the proposed method. In Fig. 5, A shows the charging machines at each end of the reactor, one of the machines being shown in greater detail in Fig. 6. Each machine slides on a horizontal guide (C, Fig. 5) which moves on vertical guides, D. Storage tubes E are provided for initial cooling of irradiated elements, which are afterwards taken to F and passed through the shielding to the coffin H for removal. Fresh fuel elements are stored at G for loading into the machine, which has a rotating magazine holding 20 fuel elements. During a fuelling sequence, the plug is first unscrewed and withdrawn, the magazine is revolved

and a new element pushed in and the plug replaced. The removal of an irradiated element follows the reverse sequence.

Control

The flow diagram (Fig. 3) has been over-simplified by the omission of much of the piping and valve-work; the reflector filling and dump arrangements are also omitted, and the diagram shows only the broad principles of control. The dump ports at the bottom of the calandria are arranged with weirs over which the heavy water flows unless restrained by the upward pressure of the helium atmosphere. This is normally set so as to allow a flow of 2,000 gal/min into the dump tank, from which it is returned to spray heads at the top of the calandria. Only a portion of the input is drawn from the dump tank, the remainder is drawn from the bottom of the calandria and cooled through a heat exchanger. A purifier of the ion-exchange type is also provided in this leg of the circuit.

The level of the moderator is changed, for control purposes, by adjusting the pressure differential between the helium in the dump tank and in the calandria vessel, which causes more or less water to flow over the weir, until equilibrium is restored at a new level. Equalizing pressure by means of the dump valve results in the immediate emptying of the calandria. The dump ports have a total cross-sectional area of 16 sq. ft and will permit a flow at the rate of 200,000 gal/min.

The moderator cooler is in no way connected with the steam system, although the heat developed in the moderator represents about 6% of the total output. The cooler is itself cooled by distilled natural water in a closed circuit with secondary heat exchangers cooled by river water; the object of this additional complication is to ensure that any leakage of heavy water can be recovered.

An alternative system of control, using neutron-absorbing rods located vertically between the calandria tubes, has been investigated.

The Windscale Report : A Summary

THE final report of the Technical Evaluation Committee on the Windscale incident (the interim report was reviewed in *Nuclear Engineering* for December, 1957, p. 510) is now available*, containing the recommendations of the Committee, based on reports by working parties on graphite, Wigner releases, cartridges, instrumentation, filters, and operational problems. The report deals with the question of Wigner release in some detail and it is considered that the simplest method of summarizing the contents is to give the Committee's recommendations and the background to each.

1. Steps should be taken to prepare for the release of Wigner Energy in Pile 2 by a combination of slow heating and BEPO techniques.

Background. A defect (i.e., Wigner growth) can be regarded as having a certain "lifetime" (or time required for the release of its stored energy) which becomes progressively shorter as graphite temperatures are raised. In the range 30°C-100°C it is reduced by a factor of about 2.5 for every 10°C rise, i.e., a defect with a lifetime of a year at 30°C can be released in a day at 100°C. Total stored energy increases with irradiation dose, but decreases considerably with the temperature at which irradiation takes place, practically no energy being stored above 400°C.

The energy stored in low-temperature reactors can be regarded for release purposes as having low-temperature (100-200°C) and high-temperature (300°C upwards) components. Release of the low-temperature component in the absence of adequate cooling would initiate a rapid divergent reaction and could result in graphite temperatures as high as 500°C. Temperatures necessary to effect a release have risen since the first time, and there has been a growing tendency, even with the higher temperatures reached, for the release to die out leaving pockets un-annealed, to add energy to subsequent releases. Since with nuclear heating the fuel temperatures are bound to be higher than the graphite, it is recommended that this be not used again.

The method evolved for BEPO involved external heating by electric heaters in the air ducts at a temperature of about 140°C, operating the reactor on low power to permit the most sensitive gas monitoring system to be used. The maximum temperature in the graphite during this release was 316°C. In the Windscale piles, however, the condition of the graphite is believed to be such that temperatures of over 400°C could be achieved.

The slow heating method aims at releasing energy by raising the temperature to about 200°C so slowly that the heat would be removed by the air flow, so that the graphite would not be appreciably hotter than the air. It is considered, however, that raising the Windscale graphite to more than 120°C would cause difficulties, particularly in stresses in the concrete structure caused by the long heating period necessary.

It is considered that a combination of the two methods might prove satisfactory. The graphite would be raised to 120°C by heated air, maintained there for 12 hours and cooled down again; then the temperature raised again, rapidly, to about 160°C. The necessary equipment for heating the air would require six to nine months to install.

2. This release should be carried out only when improved instrumentation and other modifications have been installed. The reactor should thereafter be operated normally, subject to modifications in procedure.

Background

Additional instrumentation recommended includes 100 thermocouples for fuel temperatures (200 extra for use during Wigner release) and 300 for graphite temperatures. In order that information could be immediately available to the operator, data-processing equipment would be required. More sensitive apparatus is required for fission product detection, and this must be available at all times; the scanner gear has given trouble previously through jamming due to high temperatures at Wigner release. It is also considered that more up-to-date neutron flux measuring devices are necessary.

The existing filters, while efficient, cannot prevent the escape of fission products in gaseous form. Improvements can be made but it could not be guaranteed that on a major incident, the allowable discharge would not be exceeded. However, with the operating procedure now recommended, it is difficult to see how such an incident could occur.

The existing fuel cartridges with aluminium cans are considered to be satisfactory. The present design of lithium-magnesium can is not, however, considered satisfactory and the design must be modified.

An alternative method would be to operate the pile without further Wigner release by strictly controlling the graphite temperature below the critical temperature, and would require that nowhere should the graphite temperature be allowed to rise more than 20°C above its operating temperature except at a rate of rise less than 1°C per hour. The difficulty of guaranteeing local temperature rise within this limit can be seen, and additional responsibility would be placed on the operating staff, although the difficulties are not considered insuperable.

* Cmd. 471. H.M. Stationery Office, 1s. net.

A Rolling Mill for Plutonium

The Problems of Enclosed Operation

By D. MANN (*Albert Mann's Engineering Co., Ltd.*), R. J. WAKELIN and B. J. WARD (*A.W.R.E. Aldermaston*)

Many interesting design features are incorporated in this description of modifications to a rolling mill to operate under glove-box conditions.

PLUTONIUM, as is generally known, is an alpha-emitting material of high toxicity, readily oxidized in air. Some of the oxides formed are non-adherent, hence there is a considerable health hazard associated with its handling or processing, mainly from a danger of inhalation or ingestion of airborne particles which, entering the blood stream and finding their way to the bone marrow, may cause bone cancer or leukemia.[1] The maximum permissible body burden is as low as 0.5 microgram, and it is general practice to handle plutonium-bearing materials using glove-box[2, 3] techniques.

An experimental rolling mill was required, in connection with a research programme on the plastic deformation of plutonium and its alloys, and a number of modifications in design were necessary to enable it to be installed within a glove-box enclosure. Some of the problems that were encountered were, naturally, peculiar to the existing conditions and facilities at A.W.R.E., and would not be entirely relevant to the installation of a similar mill elsewhere.

Choice of a Mill

There are many types of rolling mill commercially available which vary widely in design according to their particular application. Since the mill was required for research purposes, the basic need was for versatility, particularly in view of the severe limitations that are usually imposed upon commercial equipment when installed in a glove-box. The overall length of the mill was limited to approximately 10 ft by the dimensions of the cell allocated for the mill, which was part of the building structure. Since one function of the mill was to investigate the production of good-quality plutonium alloy sheet for deep drawing,

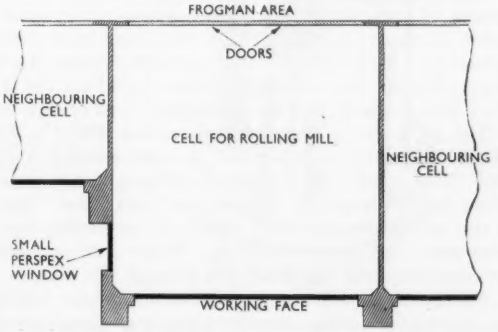


Fig. 2.—Plan of available cell.

the lengthwise dimension of the rolls needed to be in the range 6 in. to 10 in., so that sheet samples of a reasonable width for subsequent cupping experiments could be produced. These considerations eventually led to the choice of a combination 2-high/4-high mill designed by Stanat

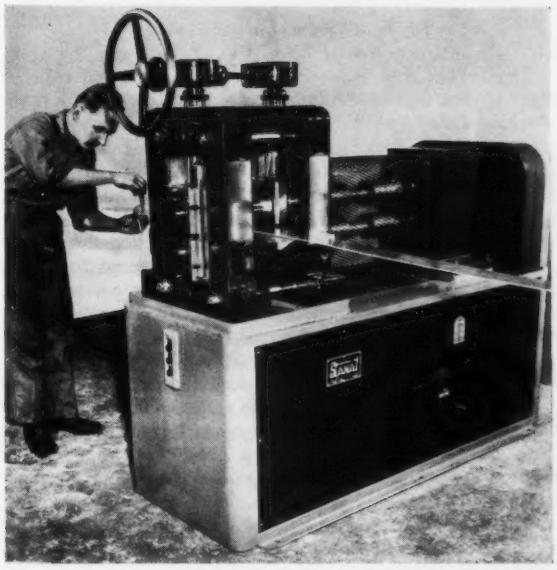


Fig. 1.—A typical standard rolling mill.

Manufacturing Co. of the U.S. and manufactured in this country by Albert Mann's Engineering Co., Ltd.

The main feature of this mill, which has proved ideal for research purposes, is that the work rolls (1½ in. diameter by 8 in. wide), in the 4-high arrangement can be quickly and easily removed, leaving the 5-in. back-up rolls to function as a conventional 2-high unit. The 4-high arrangement is particularly suited for rolling materials of low ductility. Full details of the design of the mill have been given in previous articles[4, 5] and the original commercial version, before adaptation for plutonium working, is shown in Fig. 1.

Layout of Cell

The main features of the cell which had been allocated to house the mill can be seen from the plan view in Fig. 2. It is a compartment 10 ft 6 in. square, and the mill is operated from outside the cell in the laboratory area through arm-length rubber gloves set at convenient points in Perspex panels, the maximum reach of the operator being limited to approximately 2 ft inwards from the side of the cell.

The cell, which formed an integral part of the main building structure, was not designed specifically for the mill, and only two working faces were available; the other two constituted the side walls of two neighbouring cells and were inaccessible from the laboratory. The back face, also inaccessible from the laboratory, contained two doors

which opened into a " frogman " area, i.e., an area allowed to become contaminated, in which workers suitably protected in pressurized rubber suits carry out maintenance on machinery and apparatus installed in the cells and glove-boxes. In addition, one of the working faces was, in reality, a small window.

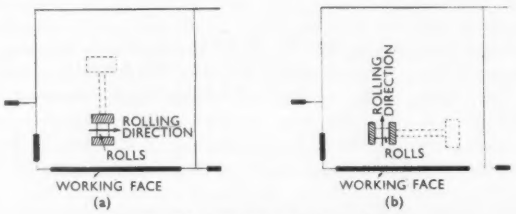


Fig. 3.—Alternative positions of mill.

The layout first considered was that with the rolls at right angles, and the rolling direction parallel to the main working face; and the mill was envisaged in some such position as shown in Fig. 3a. This layout has the advantage that, working from the front face only, the material to be rolled can be fed into the rolls on the left-hand side (say), taken out on the right-hand side, and returned by hand to the left-hand side for further rolling. The scheme was complicated, however, by the fact that the roll change procedure requires the rolls to be moved out through the side of the mill stand. To allow the necessary space for the roll change, the mill would have to be set back into the cell a considerable distance and the handling of the specimens would then be beyond reach by gloves from the working face. An operator would, therefore, be at full stretch and using tongs throughout the entire processing cycle, and, due to his side-on position, he would be unable to observe the metal as it entered the rolls. All these factors contribute to poor handling control.

The small window could not be made sufficiently wide to overcome these disadvantages, and the scheme was abandoned in favour of the general layout shown in Fig. 3b in which the rolls lie parallel to the front of the cell. The latter position gives the best control for feeding material into the rolls either by hand or by tongs; this was considered to be very important.

For roll changing, a space must be made available to move out a pair of rolls to the left-hand side of the mill stand. This is easily possible with the layout under discussion, and, in addition, the small Perspex window is conveniently positioned for reaching any controls necessary to operate the roll change mechanism.

An immediate problem arising with this layout is that, after passing through the rolls, the specimens are inaccessible from the working face and some mechanism is required to return the specimen to the entry side of the mill. A second disadvantage is that the length of specimens that can be accommodated is limited by the distance of the rolls from the working face. Since the mill is intended for research purposes only, as opposed to production work, this limitation was accepted, in view of the other advantages gained by having the rolls parallel to the working face.

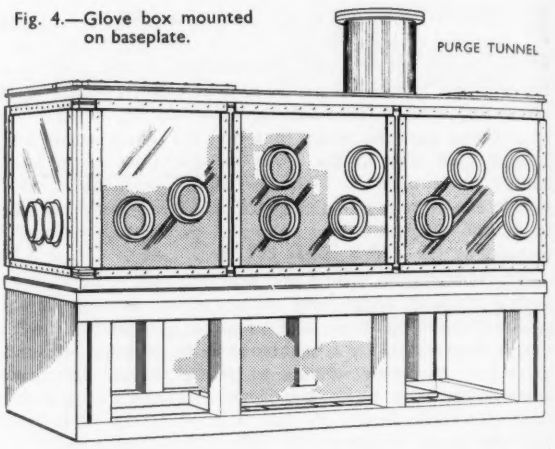
Having decided that the general scheme shown in Fig. 3b should be adopted, attention was turned to methods of roll changing, and of returning specimens from the back to the front of the mill; also to the general problem of installing the mill as a functional unit within the cell.

Design of the Glove-box

Since plutonium readily oxidizes in air and there is a danger from spontaneous combustion, it is necessary to work with the metal in an inert atmosphere. In this case argon was used, the building being equipped with a refrigeration plant for purifying and circulating high-purity argon through the active glove-boxes.

In view of the limited capacity of the plant, however, it would be unnecessarily extravagant to have an argon atmosphere in the entire cell as the volume occupied by the mill is confined to the half of the cell near the working face. The actual space required for plutonium handling is further limited to the region above the mill baseplate on which the mill stands are mounted. It was, therefore, convenient to replace the original baseplate by a wider baseplate designed to take a Perspex hood forming a glove-box which completely enclosed the rolls and upper half of the mill assembly (Fig. 4).

Fig. 4.—Glove box mounted on baseplate.



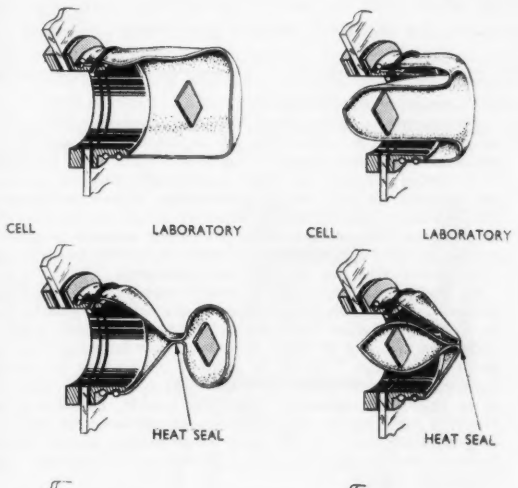
At all times when the box is in service, a flow of argon equivalent to at least two complete volume changes an hour is maintained through it. The argon in the glove-box is maintained at a pressure of -2 in. w.g., while the air in the surrounding cell is at -1 in. w.g., so that any leakage of the inner glove-box will be outwards, and the purity of the argon will be maintained, and any leakage between the outer cell and the laboratory will be inwards, preventing the spread of radioactive contamination into the laboratory. The argon enters and leaves the glove-box by 1-in. diameter " sparge " pipes, of perforated copper, running along the length of the bottom and top corner edges.

Electrical components, particularly motors, are a frequent source of trouble in argon-filled glove-boxes, since the argon atoms are readily ionized and cause breakdowns in insulation. The location of the glove-box above the baseplate obviated this difficulty, since it enabled the motor drive unit, housed beneath the baseplate, to operate in air.

The glove-box is designed and constructed to withstand heavy duty use. It consists of a rigid metal framework with three inserts of $\frac{1}{2}$-in. thick Perspex panel windows, along the full length of its front and back sides. One end is also of Perspex, the other, which is inaccessible from the laboratory, has metal panelling. Water-cooling pipes for two furnaces enter the glove-box through this panel.

The metal framework is made from welded lengths of an aluminium alloy extrusion having good corrosion resistance. Perspex (methyl methacralate) also has a good corrosion resistance. The panels were supplied to a high standard of surface finish to ensure good optical properties and ease of sealing. The glove-box is necessarily a gas-tight structure; the Perspex and metal panels are sealed to the framework, and the framework to the baseplate by moulded rubber gaskets.

Electrical services for recording devices, furnaces, thermocouples, etc., enter the glove-box via Plessey plugs mounted in the roof which is also constructed from metal and Perspex panelling; the panels forming the roof and sides of the hood being removable. This may be necessary at infrequent intervals for heavy maintenance work such as discarding and replacing a broken pair of rolls. It may also be advantageous, at some future date, to remove the back panel immediately behind the roll gap, and replace it with one specially extended to accommodate rolled products several feet in length.



(Above) Fig. 5.—Procedure for posting "out" and "in."

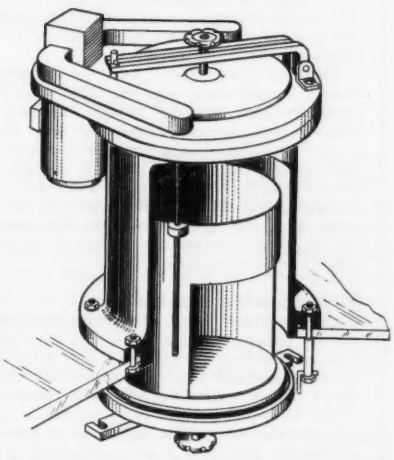


Fig. 6.—Purgeable transit tunnel.

The glove-box is capable of withstanding a differential pressure of 12 in. w.g. between the inside and outside, and is designed to have a safety factor of at least 5. The leak rate specification requires that the volume of gas leaking into the hood per hour at 3 in. w.g. depression must be less than 0.05% of the volume of the hood. If the pressure within the box rises above a specified limit whilst experiments are in progress, a high-pressure extract system and

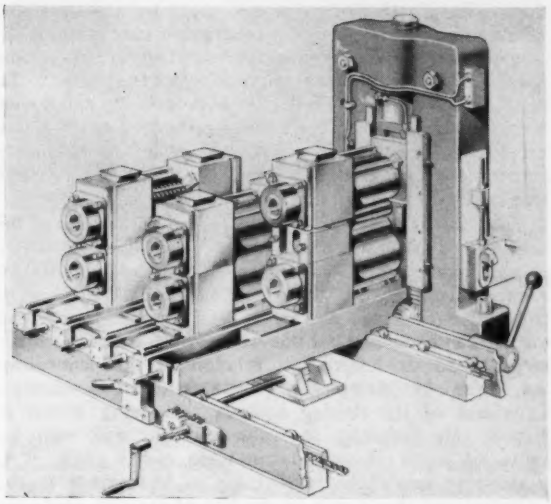


Fig. 7.—Roll change mechanism.

warning bell operate automatically. This causes a fast stream of air to be sucked through any large leak that has occurred, e.g. a split glove, and so limits the spread of contamination.

The procedure for passing objects such as ingots or rolled specimens from the laboratory area into the glove-box and vice versa is carried out in two stages. The article is first moved from the laboratory into the cell at a level above the roof of the glove-box, this being an air-to-air transition and accomplished by the standard practice of "posting," using a plastic bag which can be heat-sealed (Fig. 5). The second move involves passing objects from the cell into the glove-box and in this case the posting method has the disadvantage that air is let into the purified argon atmosphere or, in the reverse process, active argon into the cell atmosphere. A purgeable transit tunnel installed in the roof of the glove-box (Fig. 6) which can be evacuated and flushed with argon or air is, therefore, used.

Mill Adaptation for Glove-box Working

In order to have versatile rolling facilities it was essential to have more than one type of roll assembly readily available. It was decided that four sets of rolls would provide the desired flexibility, viz. grooved rolls for rod rolling, hot flat rolls, cold flat 2-high rolls and cold flat 4-high rolls. Some arrangements, therefore, had to be provided for interchanging the roll assemblies within the glove-box.

Hot rolling required a pre-heating furnace, also a vacuum annealing furnace, for the controlled annealing of cold-rolled specimens, and for recrystallization studies. In addition, shearing and cropping devices were required inside the glove-box.

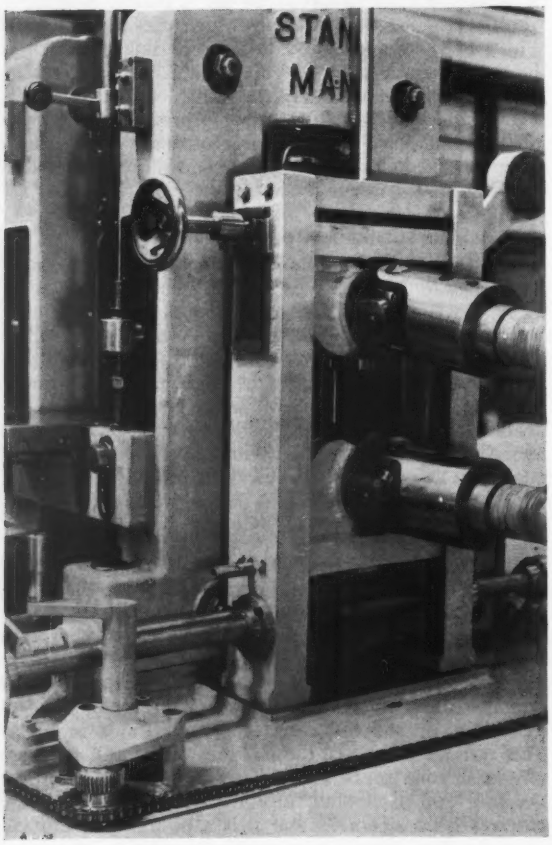
Roll-change Mechanism.—The usual method of roll-changing involving the use of cranes and pulley blocks was not considered sufficiently safe for operation inside a glove-box, since if a heavy roll slipped there was the ever-present danger that the Perspex might be cracked. The four sets of rolls, complete with their bearing chocks were each mounted on a single roll carriage. Three complete roll assemblies on the roll carriage are illustrated in Fig. 7. This carriage slides past the side face of the mill stand and any set of rolls can be selected at will. The total weight of the four roll assemblies, together with the roll selection carriage is considerable, and it is a noticeable feature of

the system that it can be moved easily by a hand-driven rack and pinion. This use of mechanical aids is important in glove-box work where the amount of effort that can be applied through gloved hands is severely limited. To facilitate removal of the roll assemblies from the mill frame, a system was designed for removing the gibs which retain the chocks longitudinally, by the movement of two easily accessible levers. One of these is shown on the right-hand side of Fig. 7.

To enable roll assemblies to pick up in the squares of the universal joints transferring the torque, it is obviously necessary to support the universal joints whilst rolls are removed from the mill, and yet enable these universal joints to be adjusted for height to suit 2- or 4-high working. An arrangement was worked out whereby the universal joints were raised or lowered in relation to the screwdown mechanism, yet clamping the universal joints to maintain alignment of the driving squares, this being shown in Fig. 8. By removing the rolls from the mill with the universal joints always at the same radial angle, it is possible to retain the relationship of the square in the universal and the square on the end of the roll, ready for re-entry, when the particular roll set removed is needed again.

Specimen Return Mechanism.—In order to return rolled specimens to the front of the glove-box, the arrangement shown in Fig. 9 was designed. This shows the mill stand without the rolls in position. The function of the device is to catch, at the 2-high position, components rolled with either the 2-high or the 4-high arrangement. The catch-tray is shown in its collecting position in Fig. 9. It is then lowered by means of the motor-driven chain and sprocket system in a forwards and downwards direction, when a plate inside the catch-tray is automatically released and may be wound forward under the mill. The rolled specimen is then within reach of the mill operator and can be re-processed.

Fig. 8.—Mill spindle supports.



Mill Drive and Controls.—The mill is driven by a 15-h.p. d.c. motor with Ward-Leonard control. The armature current is derived from an a.c. motor generator set, the excitation of the fields of both the motor and the generator being taken from the mains through half-wave thyratron rectifiers, the electronic control gear being contained in a

Un Laminoir pour Plutonium

Un Laminoir expérimental était nécessaire pour faire partie du programme de recherches sur la déformation plastique du plutonium et de ses alliages. La manutention ou le traitement de ce métal présente un risque considérable pour la santé, ce qui nécessite les plus strictes précautions, le principal danger se trouvant dans l'inhalation ou l'ingestion de particules dans l'air de plutonium qui pénètre dans le ruisseau sanguin et cause le cancer des os ou la lucémie. Le poids maximum tolérable pour le corps est aussi bas que 0,5 *microgrammes.*

La pratique à l'heure actuelle pour le maniement des matériaux portant le plutonium est d'employer des boîtes fabriquées avec du Perspex ou autre matériau transparent, avec des gants en caoutchouc le long du bras sortant de tous les parois latéraux de la boîte. Ces " boîtes de gants ", ainsi qu'on les appelle, fournissent une complète séparation physique entre l'opérateur et le matériau radioactif. Dans cet article, on accorde une attention particulière aux modifications apportées au projet et au fonctionnement d'un laminoir expérimental normal afin de faciliter son installation et son opération à l'intérieur d'une " boîte de gants ".

Plutonium-Walzvorrichtung

Es war in dem Forschungs-Programm das die plastische Umformung von Plutonium und seinen Legierungen betrifft erforderlich geworden eine Walzvorrichtung für experimentelle Zwecke zu konstruieren. Da ein beträchtliches Gesundheits-Risiko mit der Handhabung und der Behandlung dieses Metalles verbunden ist, sind strikte Vorsichtsmassregeln notwendig, wobei die Hauptgefahr das Einatmen oder die Aufnahme durch den Mund von in der Luft schwebenden Plutonium Partikeln ist; diese gehen in den Blutkreislauf über und finden ihren Weg im Körper zur Erzeugung von Knochenkrebs oder auch von Leukämie. Die grösste zulässige Menge im Körper ist ein halbes millionstel Gramm.

Die jetzt übliche Praxis Material zu handhaben, das Plutonium enthält, besteht darin, dass man Kisten aus Perspex oder anderem transparentem Material benutzt, die mit armlangen Gummi-Handschuhen versehen sind, die von den Seiten-Wandungen vorstehen. Solche sogenannten " Handschuh-Kisten " geben vollständige physische Trennung zwischen der handhabenden Person und dem radio-aktiven Material. In dem Aufsatz wird besonders auf die Modifikationen im Entwurf und im Betrieb einer normalen experimentellen Walzvorrichtung hingewiesen, die die Installation und den Betrieb im Innern einer " Handschuh-Kiste " erleichtern sollen.

Tren de Laminar para Plutonio

Como parte de un programa de investigación sobre la deformación plástica del plutonio y sus aleaciones, se necesitaba un tren de laminar experimental. Hay un considerable riesgo para la salud asociado con la manipulación o el procesado de este metal, lo que exige que se tomen precauciones muy estrictas, siendo el mayor peligro el de inhalar o ingestar las partículas de plutonio que pueden haber en el aire, el que entra en la circulación sanguínea y causa cáncer de los huesos o leucemia. La máxima cantidad tolerable en el cuerpo es tan baja como 0,5 *microgramos.*

Es ahora la práctica general manejar materiales conteniendo plutonio en cajas hechas de " Perspex " u otro material transparente, con guantes de caucho del largo del brazo sobresaliendo de las paredes laterales de la caja. Estas así llamadas " cajas de guantes " proveen separación física completa entre el operador y el material radioactivo. En este artícula se presta particular atención a las modificaciones en el diseño y el funcionamiento de un tren de laminar experimental normal para facilitar su instalación y operación dentro de una " caja de guantes ".

cabinet sited in the clean laboratory. Automatic fault indication, by means of neon lamp indicators, is provided, and the cabinet itself is pressurized to exclude dust.

The control equipment is arranged to give an infinitely variable, stabilized roll speed from zero to 75 ft/min. A mobile control desk, connected by plug-in cables, contains a mill motor ammeter, a speed indicator, roll pressure indicator and roll neck torque indicator. Push-button control is provided for forward running, forward inching, stopping, reverse inching, and reverse running. Inching is at crawl speed, independently adjustable. The mill motor is protected, through the electronic control gear against overloading.

Instrumentation.—A comprehensive system of instrumentation is fitted allowing left-hand or right-hand roll pressure, or the sum of both, to be read at the control desk. These pressures are measured by load cells situated between the screwdown and top roll chocks.

Fig. 9.—Specimen return mechanism.

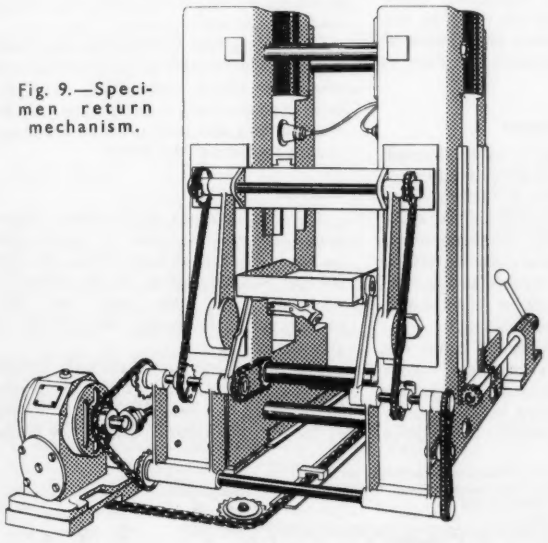


FIGURE 11(a)

Measurements can also be made of the upper roll neck torque, lower roll neck torque and the sum of both. These are measured on the driving spindles, by strain gauges, the signals being transmitted via silver sliprings and graphite brushes at the pinion stand (Fig. 10). A high-speed pen recorder is provided at the control desk, for the recording of the roll pressure and roll neck torque. As the length of the component available for processing may at times be very small, and as the mill will roll at up to 75 ft/min it was necessary to arrange for very quick response of the roll pressure and torque recording.

Ancillary Equipment.—Two electrical resistance furnaces are installed within the glove-box. One, a 3-kW argon-filled rectangular muffle furnace, is situated horizontally above the universal spindles, and used for heating specimens prior to hot rolling. This furnace, with internal dimensions 3 in. by 7½ in. by 24 in., can accommodate the maximum size of specimen which can be passed through the rolls, and is placed at a convenient angle for manipulating specimens from the furnace into the roll gap. A vertical tubular furnace is available for annealing and recrystallization

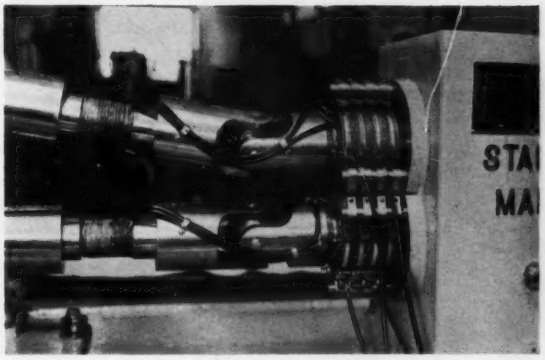
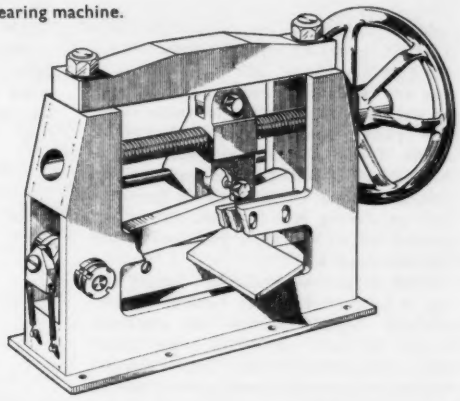


Fig. 10.—Torque measuring equipment.

studies. The furnace tube may be evacuated with a vacuum unit situated below the mill baseplate and experiments may be conducted either in an argon atmosphere or under vacuum.

Some provision was necessary for cutting sheet and rod specimens within the glove-box. The available space and degree of arm movement were both insufficient to install a guillotine of suitable size for shearing sheet specimens, and a shearing machine operated by a hand wheel, was developed to overcome the awkward lever movement associated with an orthodox guillotine. Due to its compactness and high mechanical advantage this machine, shown in Fig. 11, is ideal for glove-box operation. Further economy in space

Fig. 11.—Shearing machine.



is gained by having a simple rod cropping machine which may be installed when the rod rolls are in position and removed again on reverting to sheet rolling.

Acknowledgments

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THE G.E.C. CRANE AT HUNTERSTON

Hoisting the bridge into place.

SECOND of the "giants" to be commissioned, and now the largest crane in the country, is that at the Hunterston power station, which has been erected in 5½ months. Weighing 1,200 tons itself, the crane is designed for normal loads up to 300 tons, but 350 tons can be lifted in special circumstances. The height overall is 270 ft and the span 200 ft.

As can be seen from the accompanying illustrations, the crane has remarkably clean lines, the legs being built up of box girders, instead of the more conventional open construction. The leg structure at one end is braced to withstand horizontal as well as vertical loads; the space above this bracing, outside the main span of the crane, forms a parking space for the main crabs, of which there are two. An auxiliary crane, of the fixed-jib (i.e. non-luffing) slewing type is, when not in use, parked on an outrigger platform above the unbraced leg.

Each of the two columns forming one leg is supported at the bottom on two 4-wheel bogies through an equalizer beam, the pairs of bogies being joined with a pin-jointed boom. Double flanged wheels are provided, running on a pair of rails 1,000 ft long, on either side of the reactor area; the long travel motors drive the two inner bogies on each side; all four wheels of the drive bogies being driven through spur and bevel gears.

Hoisting

An interesting feature of the design is that the hoist motors do not form a part of the crabs themselves, but are carried at ground level on bogies in between the legs on either side of the crane. There are two drums for each hoist, and the ropes pass upwards and over sheaves on the bridge structure, through sheaves on one of the crabs and its hook, and are attached to equalizer bars at the other end of the bridge. Both of the crabs run on the same rails and can be used simultaneously, their hooks can approach each other to a minimum distance of 20 ft. The auxiliary crane runs on the same rails as the main crab, and is not intended for simultaneous use. It carries its own hoisting motor which drives either a 30 ton or 5 ton hoist, changeover being manually effected from the rear of the slewing platform. Powers and speeds of the various crane movements are given in Table 1.

Power Supply and Control

A 415 V 3-ph. supply is taken through a 3-core flexible cable from near the mid-point of the track, via a reeling drum on a trolley attached to one of the main bogies. Since all except the long travel motors are d.c., a mercury arc rectifier is mounted on the same trolley as the reeling drum, together with a small transformer for lighting and heating.

Where large differences of cable run exist between motors requiring close speed matching, additional compensating impedance is inserted in the shorter run. The long travel motors are kept in step to prevent cross-winding of the crane, by Magslip transmitters on the leading (idling) wheels, any misalignment causing the "fast" motors to slow down.

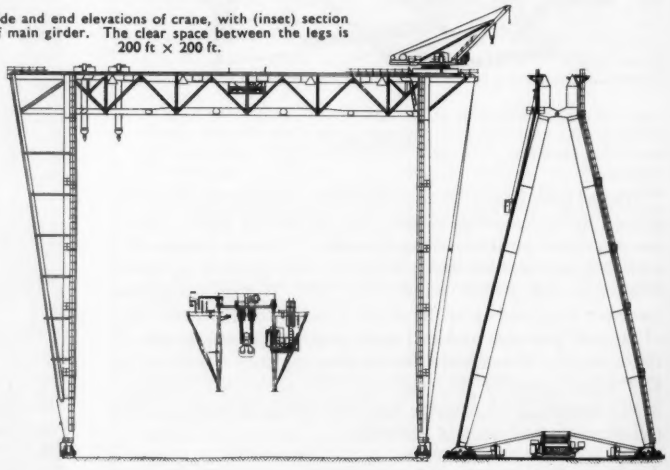
The main control cabin does not move with the crabs, but is permanently located at the centre of the bridge and is equipped with standard drum controllers for hoist and cross traverse of each crab and long travel of the crane. The auxiliary crane has a cab at the front of the slewing platform, under the jib and is fitted with cam-type controllers mounted in the arms of the driver's chair. All hooks are equipped with indicators of the load cell pattern.

Communication between the driver and slinger is by means of a carrier-current telephone system, operating over the main power line; a telephone can be plugged into any point on the site power system to contact the driver.

Erection

The leg columns and bridge girders were delivered to site in partly-built sections about 40 ft long. When the first column was assembled on the ground, it was raised by gin poles and after assembling to its bogie, was secured by guy ropes.

The bridge was simultaneously erected on the ground, and, after temporary frameworks had been installed at the top of the legs, the central span of the bridge complete with its own auxiliary crane was raised into position by its own hoist motors.



Side and end elevations of crane, with (inset) section of main girder. The clear space between the legs is 200 ft × 200 ft.

The crane was designed to the specification of the General Electric Co., Ltd., by the Société Applevage of Paris, who also supplied the structure. Erection was carried out by the Motherwell Bridge and Engineering Co., Ltd.

TABLE 1.—Crane Ratings

Main Crane (2 Crabs)		
Design load and lifting speed	150 tons	6 ft/min
Main hoist motor	100 h.p.	
Cross traverse power and speed	25 h.p.	45 ft/min
Long travel power and speed	4×45 h.p.	65 ft/min
Auxiliary Crane (30- and 5-ton hoists)		
Design load and speed, with common 100 h.p. hoist motor	30 tons	30 ft/min
	5 tons	180 ft/min
Cross traverse power and speed	25 h.p.	100 ft/min
Slewing power and speed	25 h.p.	1.5 r.p.m.

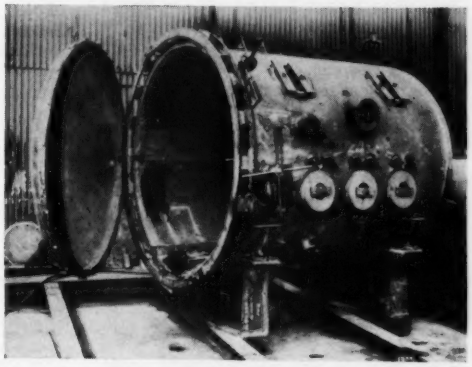
Nuclear Plant at the Chemical Exhibition

INEVITABLY there was plenty of evidence of the influence of nuclear engineering at the recent Chemical and Petroleum Engineering Exhibition (Olympia, London, June 18 to 28). Most of the British nuclear reactor construction consortia were represented by specialist member companies themselves actively engaged in petroleum and chemical engineering. Although specific nuclear exhibits were not necessarily prominently displayed on their stands it was noteworthy that many visitors to the exhibition were anxious to talk about nuclear engineering developments.

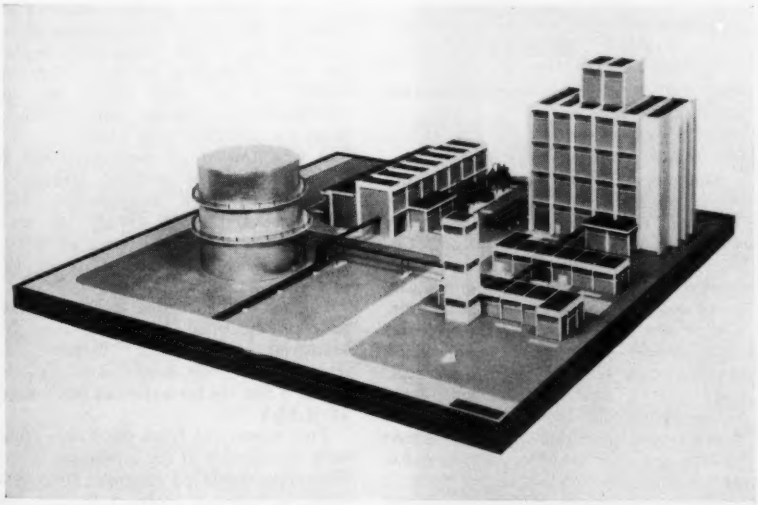
Over a third of the 300 exhibitors were already making a direct contribution to nuclear engineering and many of the others have handled sub-contracts for the industry from time to time.

Heavy Water

Of prime interest was the stand of Petrocarbon Developments where a model of a plant for heavy water production by hydrogen distillation could be seen. The Petrocarbon process is based on a scheme originally developed by the U.K.A.E.A. The process involves cooling down the incoming hydrogen stream to −251°C, at which temperature all impurities are solid. The gas then enters a series of fractionating columns, giving a final product containing 90% HD, which is burnt with oxygen, giving 45% heavy water. This is fractionated in high efficiency water stills to a final concentration of 99.8%. Refrigeration at the lowest temperatures is obtained by an auxiliary circuit using hydrogen of very high purity, which is expanded through turbines of special design. The whole process operates at a low pressure, less than 10 atmospheres, and has a low power consumption compared with alternative methods. Simon-Carves have been appointed exclusive engineering contractors for plants to the Petrocarbon design. Daniel Adamson and Co.—members of the Humphreys and Glasgow-Alco nuclear consortia — featured several examples of longitudinally finned tubes in various ferrous and non-ferrous metals. The company is installing plant for the large-scale production of this type of finning which is produced by welding U-form channel to a parent tube. The process, which was originated by Alco Products gives good heat transfer at low cost. This system was first reviewed in *Nuclear Engineering* for August, 1956, p. 203.



Ring clamp boltless door on pressure vessel, as shown by Robert Jenkins, Ltd.



This model of the Petrocarbon plant for heavy water production by hydrogen distillation was prominently displayed on the company's stand at the exhibition.

Valves

As might be expected there was a profusion of new valves. Flight Refuelling introduced a new solenoid-operated 8-in. unit particularly suitable for hydrant systems where emergency shut down is frequently required. British Steam Specialities showed, for the first time, a new design of high-pressure bonnetless gate valve for pressures of up to 1,500 p.s.i. and temperatures of up to 770°F. Audley Engineering featured the unique Annin Domotor control valve which the company is making under licence from the Annin Co. of Los Angeles.

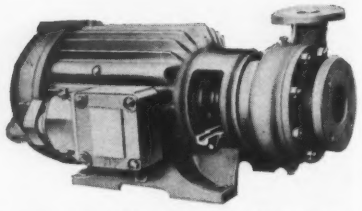
New products on the stand of Fisher Governor included the 340 and 350 electro-hydraulic valve actuators. Recent trends towards electrical control loops have created a demand for final control elements capable of using a greater transmission speed. Fisher have therefore developed a simple force motor which controls a hydraulic pilot: two types cover valve sizes from ½ in. to 16 in.

Fabrication Methods

An interesting aspect was the large number of exhibitors with capacity for special forms of construction—a frequent requirement in nuclear engineering. A.P.V., for instance, showed examples of welded fabrications in aluminium and stainless steel. Towler and Son had both welded- and riveted-steel platework on their stand and the company has capacity for homogeneous lead lining and chemical leadwork.

Another company specializing in large

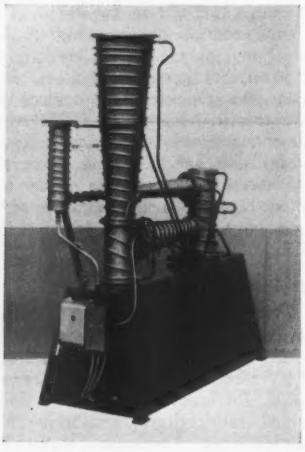
fabrications, G. A. Harvey and Co., exhibited a section of a pressure vessel set up for radiographic examination of the welds using Panatron equipment for gamma radiation developed by their associates, Nuclear Engineering.



The new Worthington-Simpson Monobloc flameproof pump for the chemical industry.

The patented ring clamp boltless door devised by Robert Jenkins and Co. makes possible considerable savings in labour and process time on vessels which require frequent opening.

The ring clamp consists of a number of mild-steel clamps, between two mild-steel rings, arranged at similar intervals to notches in the flange of the door. Each notch is wide enough to allow a clamp tongue to pass through when the door is to be opened or closed. By rotating the ring clamp a short distance, the clamp tongues engage the tongues of the door flange. The opposing tongues take the pressure load on the door while a rubber gasket ensures a positive pressure seal. The door itself does not rotate so there is no wear on the sealing gasket. The small amount of movement required by the ring clamp for opening and closing the door can be achieved manually, or mechanically by electric, pneumatic or hydraulic equipment. Special locking devices and safety bars ensure that the ring clamp will not move while the vessel is under pressure. Ring clamp boltless doors are available with bolting flanges for converting existing process vessels to this system.

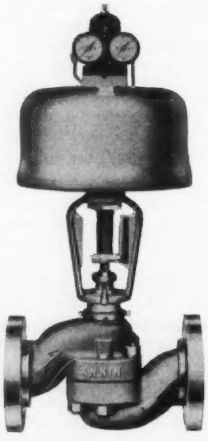


A booster vapour pump developed by Edwards High Vacuum for large-scale plant. A peak speed of 4,500 litres/sec is achieved for air, and twice that speed for hydrogen.

Instrumentation

There were many companies exhibiting new developments in instrumentation. Taylor Controls, for example, has developed a new miniature recorder known as the Transcope. The unit only requires a 6-in. by 6-in. aperture, yet contains a full range of facilities: Servomatic power pens, 0.1% threshold sensitivity, 4-in. 30-day chart, electrical or pneumatic integral alarms, complete cascade system, ability to handle three variables and forward control settings.

The new mercury-less bellows type diaphragm flow meter by Foxboro-Yoxall measures a range of differential pressures from 20-200 inches of water at static pressures up to 2,000 p.s.i. Other features of this new mercury-less meter (the type 37) are a frictionless flexure pivoted drive unit; positive protection against over-range; a simple method of range change; full externally adjustable range damping and built-in temperature compensation for all differential ranges.

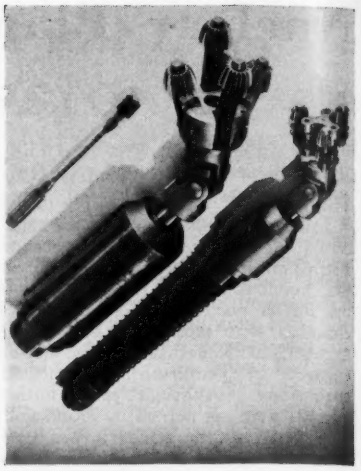


Audco Annin valve made under licence by Audley Engineering Co.

Gasholder

Although not new, there was a model of the Wiggins dry-seal gasholder on the joint stand of the Power-Gas Corporation and Ashmore, Benson, Pease and Co. With this type of gasholder a frictionless movable piston floats on the confined gas, rising and falling with changes in volume. The annular space between the piston and the gasholder shell is completely sealed by a synthetic rubber coated fabric seal. For handling exceptionally pure gases the gasholder can be in stainless steel. A number of small capacity Wiggins gasholders are used by the Authority for storage purposes.

New pumps by Worthington-Simpson included a flame-proof Monobloc unit and a pump in Hastelloy B—the latest addition to the company's range of chemical pumps. A range of pumps for handling volatile or corrosive liquids, the Mopump series was shown by Rhodes, Brydon and Youatt.



Selection from the Lagonda range of tube cleaning equipment made by Consolidated Pneumatic Tool Co.

Electrodes featured by Murex Welding Processes included the Nicrex which was used for welding the stainless steel reactor vessel of the fast breeder at Dounreay. From their wide range of welders, Lincoln Electric chose to demonstrate the new C.V. 750 constant voltage generator for submerged arc automatic welding.

Tube Cleaning

An important facet of chemical engineering is the need for tube cleaning equipment. Industrial Descaling Tools featured their Lark tube cleaners, pneumatic and electrically driven, for descaling tubes from $\frac{1}{2}$ in. to 16 in. General Descaling also displayed a wide variety of pipe cleaning devices whilst Consolidated Pneumatic showed some of the Lagonda equipment which the company are now producing at their Aberdeen works. In an allied sphere was the shot-blasting equipment made by Vacu-Blast for descaling large plates.

A new flow-cooled mechanical seal by Flexibox operates without leakage at exceptionally high temperatures, high pressures and high speeds of shaft rotation. Temperatures of over 800°F. and pressures of up to 800 p.s.i.g. can safely be handled.

Isopad, who specialize in the construction of electrical heating devices for industrial applications, featured an interesting surface heater developed for use in a test rig for valves of 60-in. bore, 15 ft high.

Two companies from the Vokes group were represented at the exhibition. Vokes Genspring displayed examples from their range of constant support hangers and the parent company included some recently developed filters in their wide range of products.

The Blower Plant at Windscale

Some Facts and Figures

WITH the publication of the final Report on the Windscale reactors, and the knowledge that one—and possibly both—may not be re-started, it seems an appropriate time to publish information on the blower installation, details of which have hitherto been withheld for security reasons. The Windscale blower installation would be interesting even if only on account of its sheer size, the eight blowers for each reactor totalling more than 21,000 h.p., and being capable of delivering nearly 2,000,000 cu. ft/min at a pressure of 60 in. w.g. The blowers are arranged in groups of four on either side of the reactor. In addition, four shut-down fans were provided for use when the reactor is shut down and the pile is not operating, as well as two booster fans to maintain air pressure in the charge area above that in the pile.

The blowers were manufactured by James Howden and Co., Ltd., to a rigid specification which included an air volume between 97% and 103% of the specified figure, and an efficiency of not less than 97% of that quoted, when calculated in accordance with B.S.848.

Construction

The blowers are of the double open inlet centrifugal type, with backward aerofoil blading. The impellers are fabricated from Colville Ducol W27, riveted to cast steel hubs keyed to forged shafts. All welding was subject to a rigid specification and complete radiographic examination, and the impellers which are 10 ft diameter, were run after balancing for 48 hours at 25% overspeed.

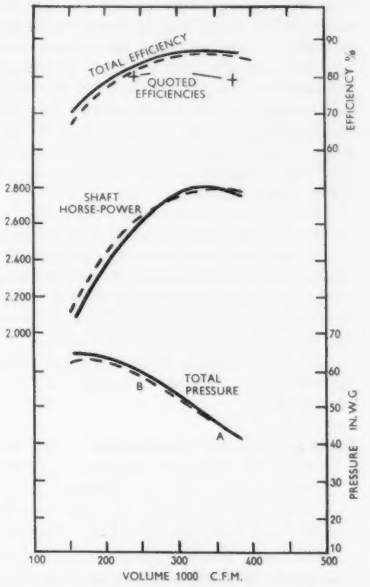
The casings are split on the horizontal centre line, and are fabricated from m.s. plate and rolled section stiffeners. All parts of the blower in the air stream were shot-blasted and sprayed with aluminium 0.007 in. minimum thickness.

Bearings are of the spherical-seat type with white-metal sleeves, and forced lubrication with interlocks to prevent starting unless the lubrication system is up to pressure, low-pressure alarms being fitted. Each blower is driven through a Wellman-Bibby flexible coupling by a Mather and Platt induction motor rated at 2,400 h.p. at 900 r.p.m., with a continuous maximum rating of 2,640 h.p. with a temperature rise of 60°C after 6 hours.

Control

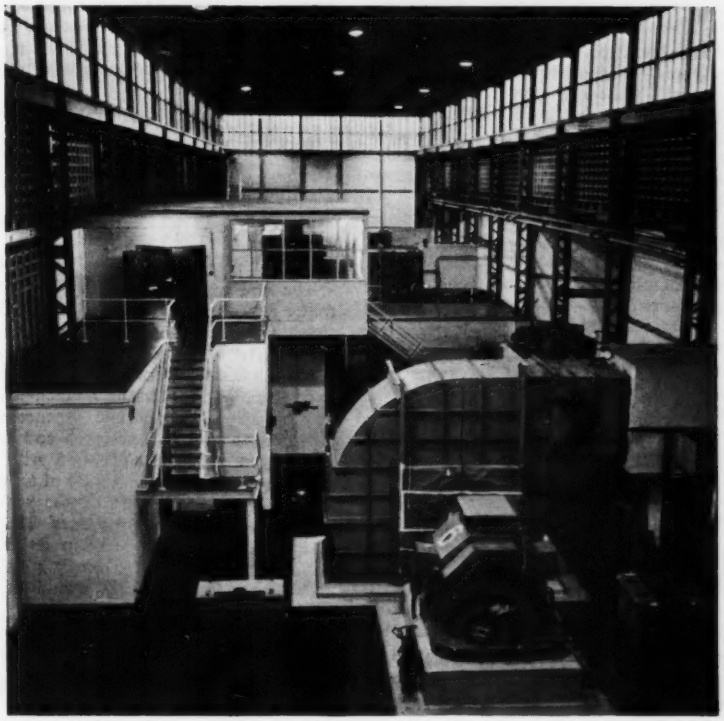
The 11 kV switchgear for the motors is of Reyrolle manufacture and the motor units are interlocked so that it is impossible to start the blowers if the charge area doors are open. If one booster fan were to fail, the second, or standby unit, is brought into service automatically. If the shutdown fans on one side of the pile fail to open their dampers, all shutdown and booster fans stop. Similarly, if the standby booster should fail to start, all shutdown fans stop.

As it is essential that air be always fed from both sides of the pile, the starting of any one has to be accompanied by the starting of the corresponding blower on the other side of the pile. This is under the control of the blower room staff, but interlocks are provided to ensure that any blower cannot run alone continuously.



(Above) Performance curves on acceptance tests of two units at 990 r.p.m., with atmospheric conditions of 50°F and 30 in. Hg. Points A and B represent the initial and ultimate conditions specified.

(Below) A view in one of the blower houses.



Performance Tests

A 2-ft-diameter model of the main blowers was built and tested in Howden's research laboratory and the performance was found to be better than quoted. The pressure/volume characteristic passed through the ultimate duty, "b," but with a smaller absorbed horse-power; and at the initial duty, "a," the pressure/volume ratio was higher than that quoted.

The final performance obtained at site for two units is shown in the curves from which it will be noted that the performances are very similar and in each case the efficiency is higher than originally specified. At the time of their installation, these blowers were the most efficient in the world for their specified power.

NEW BOOKS

Radioisotope Laboratory Techniques. By R. A. Faires and B. H. Parks. (244 pp., 94 illus. + appendices.) George Newnes, Ltd. 25s. net.

Long experience of the Isotope School at Harwell has enabled the authors to bring a practical approach to the *use* of isotopes. While much has been written on radioactivity in general little has been published for the man in the laboratory, and it is as a manual for the technologist that this book has been written.

There are introductory chapters on the elements of nuclear physics, properties of radiation, isotope production and health physics, followed by several chapters on the laboratory, including hazard control, waste disposal and decontamination and apparatus. Several chapters are devoted to electronic techniques and their applications in detection and counting. Chemical applications, gamma-ray and auto-radiography and general applications of isotopes are all faithfully dealt with. There are several appendices, including tables of useful isotopes and their characteristics.

While the book can in no case be called superficial, the approach throughout has been very cleverly kept at a level that enables the whole field to be surveyed within a book of modest dimensions at a reasonable price.

An Introduction to Fluid Mechanics and Heat Transfer. By Prof. J. M. Kay, M.A., Ph.D. (309 pp., 118 illus. + 40 unworked examples.) Cambridge University Press. 37s. 6d. net.

This book gives all the analytical work in these two subjects that most mechanical engineers will require before specializing. Dr. Kay is Professor of Nuclear Power at Imperial College, and the coupling of the two subjects is, of course, particularly relevant to the design of economic reactor cooling systems.

The book is well written, with clear development and illustration of each section. Seven chapters cover hydraulics in the older engineering sense, with application to channel flow, weirs, pumps, compressors and fans. Four chapters deal with fluid mechanics theory, including compressible flow. Diffusion, solids in fluid flow and flow through packed beds are each given a chapter, and amongst the rest seven chapters develop the heat transfer side in step. There are four appendices of particular advanced work, one giving a valuable engineer's guide to vector analysis.

Included in the book is all the basic fluid mechanics normally required by mechanical engineers, together with much basic work for civil problems. For the latter, Jameson's "Introduction" can be said to have served well, but for mechanicals a similar work, presenting a text which is satisfactory for beginners and can retain their subsequent respect in use, has not previously been achieved and the present work can be recommended as now filling that need. Its heat transfer material is naturally of more advanced interest, but the fluid mechanics side more than provides an introduction to the wealth of recent advanced publications available—such as Prandtl's "Essentials of Fluid Dynamics" and the books edited and written by Rouse, Jaeger and Goldstein with their varying interests ranging from aeronautics to water power theory.

The author's inclusion of only 40 examples, and these unsolved, is perhaps a reasonable economy for present-day teaching needs, as examination standards vary and many examining bodies make available typical questions with answers for the unguided student and teacher.

For a new book, with the high costs obtaining at present, its price is very reasonable. S.H.W.

Nuclear Reactor Experiments. By the Staff of Argonne National Laboratory, edited by J. Barton Hoag. (480 pp., 245 illus. + appendices.) D. Van Nostrand Co. Ltd. 51s. net.

This book, like the previous review on this page, is also a laboratory manual, intended to give a broad insight into the problems involved in reactor design, construction, and operation.

An introduction covering basic information on particles, radioactive decay, cross sections and the fundamentals of irradiation, is followed by chapters on radiation detection and measurement. Forty-nine experiments are described, on moderator assemblies, sub-critical assemblies and operating reactors, and include work on cross-section measurements, on heat removal, fuel preparation, corrosion and radiation effects and separation processes. Most of the experiments have been written by ANL staff who either created or helped to create the work they describe, and no fewer than 44 persons have contributed. Appendices cover such useful items as abbreviations, conversion tables for energy units, decay and exposure facts for indium and gold, properties of heavy water, thermocouple calibration data, etc.

The book will appeal to engineers and scientists anxious to widen their horizon in the reactor field.

The 1958/9 Communications and Electronics Buyers' Guide, Who's Who and Reference Book. Edited by C. C. Gee. (520 pp.) Heywood and Co. Ltd. £5 5s. net.

Under the direction of the editor of *British Communications and Electronics*, this book, which is the result of some four years' research, answers the question, "What is the British electronics industry?" bringing together in a single volume a mass of essential information on the products, manufacturers and personalities of the industry, with technical, statistical and other data, including a reference section with a number of product surveys in which 1,956 specific products are referred to in 76 pages of tables. The "Who's Who" section shows the present position and qualifications of over 1,800 individuals associated with British electronics.

O.E.E.C. Publications

First Report of the Steering Committee

The first report of the Steering Committee for Nuclear Energy to the O.E.E.C. Council has now been published under the title "European Nuclear Energy Agency and the Eurochemic Company." It details organization and financing of a 100-ton/year Eurochemic processing plant, to operate as a research and pilot plant from 1960-61 to 1964-65 with an annual operational expenditure of around $3 M. Towards the end of the period, earnings are expected to exceed $1½ M. The site chosen is at Mol, in Belgium, but, if construction of a larger plant is undertaken, this probably would be in Norway.

Recommendations are made on reactors to be constructed, priority being given to a light water moderated, high flux materials testing reactor of 50 to 100 MW power. Initiation of the homogenous reactor project for Winfrith Heath is strongly recommended. Preliminary agreement has been reached with the A.E.A. on this project and final plans are to be submitted this summer. Longer-term studies proposed relate to liquid metal fuelled and fast breeder systems.

Catalogue of Courses on Nuclear Energy in O.E.E.C. Countries

This modest title covers a 115-page publication giving a list of courses on nuclear energy and related subjects throughout Universities, technical schools and research centres of Western Europe. The countries covered are Austria, Belgium, Denmark, France, Germany, Greece, Ireland, Italy, Netherlands, Norway, Portugal, Sweden, Switzerland and Turkey, in addition to the U.K.

Filters for CO_2 Circuits

New Range designed for Power Reactors

A RANGE of filters for removing fine dust particles entrained in the CO_2 gas of a reactor circuit has recently been evolved by Mancuna Engineering of Manchester. Built to be in accordance with the requirements of the various U.K. nuclear power consortia, the Mancuna filters are designed to have a high collection efficiency of fine dust particles at a constant resistance, with 100% availability for the entire life of the unit. Specific applications include filters for the following CO_2 circuits: blow-down (D.560 Mk. IIB), relief valve (D.560 Mk. IIA), overfill (D.560 single tube) and by-pass, drier and charge-discharge (D.450 Mk. III).

Each unit consists of a series of cyclones to a proved basic design, the aerodynamic properties of which have given dust collecting efficiencies far higher than hitherto thought possible with mechanical filters.

Unit D.560 is cast as a whole in stainless steel, but with the D.450, each cyclone, body, cover and inlet is individually cast on the shell-moulded principle, in Meehanite iron, and then assembled on ground faces to ensure maximum accuracy. The volume of each inlet and cyclone is thus identical, therefore the resistance cyclones must also be identical. The flow rate and dust loading through each cyclone is balanced and however many are assembled in a single unit, the performance will remain constant. This can be more easily understood by reference to Fig. 1.

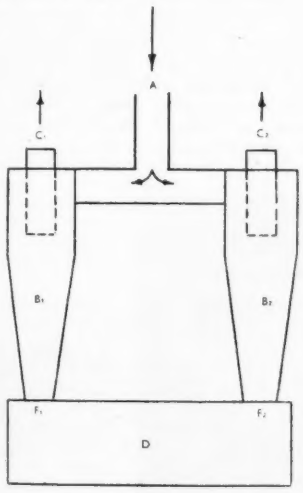


Fig. 1.

Take a common inlet A, feeding two cyclones, B_1 and B_2, discharging dust to hopper D and cleaned gas through outlets C_1 and C_2. If both cyclones are identical, then the flow rate at C_1 and C_2 will be identical and the trapped gas in the hopper D will remain in equilibrium, as the pressure at points F_1 and F_2 must be the same. If, however, two different cyclones are used and the resistance in B_2 is lower than in cyclone B_1, the gas in hopper D will no longer be in equilibrium, consequently the pressure at point F_2 will be less than the pressure at point F_1, with the result that there will be gas flow through the hopper from cyclone B_1 to cyclone B_2, carrying with it dust from the hopper. The operational efficiency of multi-cyclone filters is dependent to a large extent on this single feature.

The efficiency of an individual cyclone, of course, is related to the diameter and the accuracy of the internal concentricity. The higher the gas volume and the smaller the cyclone, the higher the efficiency. The higher the gas velocity, the greater is the need for true concentricity and a smooth surface.

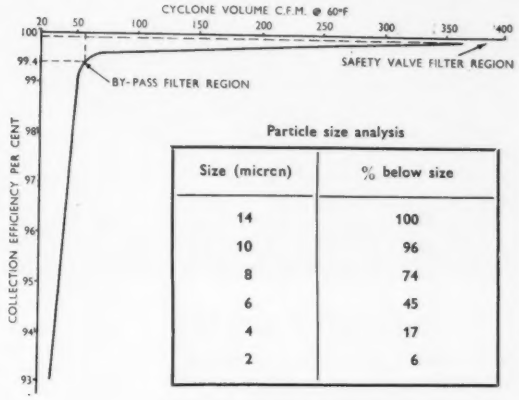


Fig. 2. — Collection efficiency/cyclone volume for D.450 collector with Aloxite grade 50 optical powder.

Particle size analysis

Size (micron)	% below size
14	100
10	96
8	74
6	45
4	17
2	6

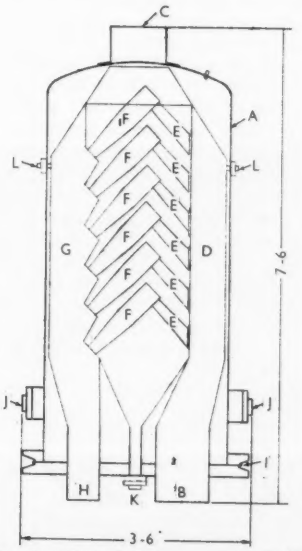


Fig. 3.—Typical by-pass unit, D.450 Mk. IIB, 24 tube, 27 lb/sec at 150 p.s.i., 200°C. Pressure drop 4.5 p.s.i.

A. Pressure vessel. B. Gas inlet. C. Gas outlet. D. Gas inlet manifold. E. Cyclone inlets. F. Cyclones. G. Dust outlet manifold. H. Dust outlet. I. Seal welded flange. J. Side connections for blowing down. K. Bottom connections for blowing down. L. Anti-vibration screws.

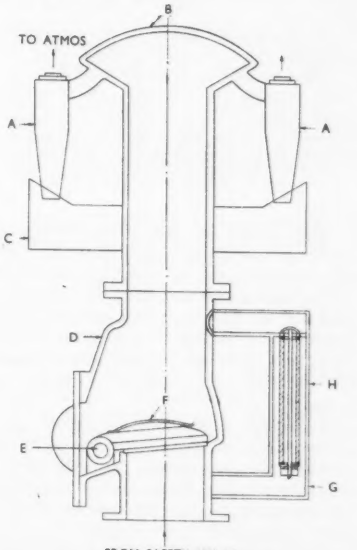


Fig. 4.—Typical relief valve filter D.560 Mk. IIA, 14 tube, 103,000 lb/hr at 150 p.s.i., 390°C. Pressure drop 40 p.s.i.

A. Cyclones. B. Gas inlet manifold sphere. C. Dust hopper. D. By-pass valve. E. Hinge. F. Spring damper. G. By-pass. H. 1-18 in. ceramic tube.

The normal inlet velocity of a D.450 cyclone is between 55 and 70 ft/sec. During Mancuna's research into the

design of filters for CO_2 gas-cooled reactors, cyclones were tested at inlet velocities of 600 ft/sec. Throughout this range the efficiency on a test dust smaller than 13 micron and containing sub-micron particles, increased from 99.4% at 55 ft/sec to 99.87% at 600 ft/sec.

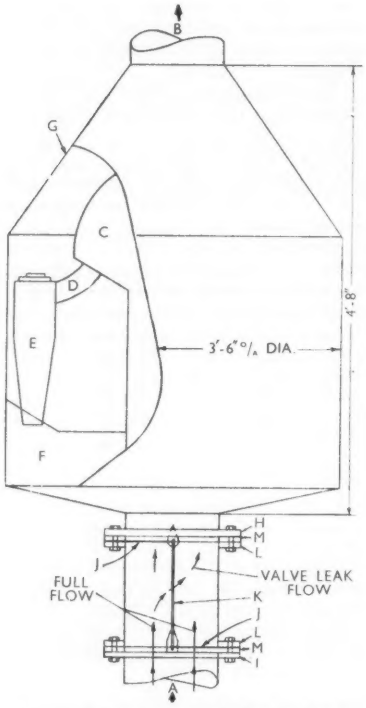


Fig. 5.—Typical safety relief valve filter D.560 Mk.II, 14 tube, 103,000 lb/h at 150 p.s.i., 390°C. Pressure drop 40 p.s.i.

A. Gas inlet. B. Gas outlet. C. Gas inlet manifold sphere. D. Cyclone inlet. E. Cyclones. F. Dust hopper. G. Outer cover. H. Filter inlet flange. I. Safety valve outlet pipe. J. Bursting disc. K. Ceramic. L. Body and flange of valve leak filter. M. End clamping ring and ceramic support.

The design of the Mancuna-Dustex D.560 Blow-down and Relief Valve filters makes use of extremely high gas velocities for two reasons: firstly to reduce the size of the filters to a minimum and secondly to maintain a high collecting efficiency from full pressure of the system to as near atmospheric pressure as possible.

Each unit is designed to operate at a pressure loss of 50 p.s.i. maximum, at full system pressure, giving an inlet linear velocity of 600 ft/sec and a collecting efficiency on standard test dust of 99.87%. An automatic low volume by-pass ceramic filter on the inlet of the multi-cyclone unit comes into operation if the gas flow is reduced to the point where the cyclone collecting efficiency will drop below 99%. This can happen on a relief valve should this not seat properly after a discharge and in the case of the blow-down filters, when the system has exhausted to nearly atmospheric pressure and before the vacuum pumps are put on, and the final exhausting to 28 in. of mercury when the flow rate will gradually drop to zero.

D.450 filters designed for by-pass and drier applications are similar in performance in many ways to the blow-down and relief-valve filters. They are contained in a pressure vessel but operate at much reduced velocities and under comparatively constant load, with a pressure loss of 1 p.s.i. to 5 p.s.i.

The Rome Nuclear Exhibition

IN view of the rapidly expanding market for nuclear engineering in Italy, the 5th Electronic Congress and Nuclear Exhibition which opened in Rome on June 17 acquired even greater significance for British manufacturers. Although direct British participation was small, at least one stand attracted a great deal of attention to the progress that U.K. manufacturers have already made. The principal British company represented was Nuclear Power Plant, who shared a stand with their Italian associates Agip Nucleare of Milan. N.P.P.C. recently signed an agreement with Agip Nucleare for collaboration in the design of nuclear power stations in Italy. This agreement will be followed by a contract for the construction of a station with an output of 200 MW (a single gas-cooled, graphite-moderated reactor) which will be built at Latina, some 40 miles south of Rome.

Site work at Latina has, in fact, already commenced with N.P.P.C. carrying out soil analysis tests and preliminary construction of site roads. The excavation work proper will start in September.

The main exhibit on the stand (supplied by N.P.P.C.) was a model of a complete nuclear power station. There were two gas-cooled, graphite-moderated reactors, sectioned and animated to display working principles and layout, a fully equipped turbine house and a switchyard. The model, measuring 12 ft by 12 ft, included the circulating water pump-house, cooling pond and other miscellaneous buildings.

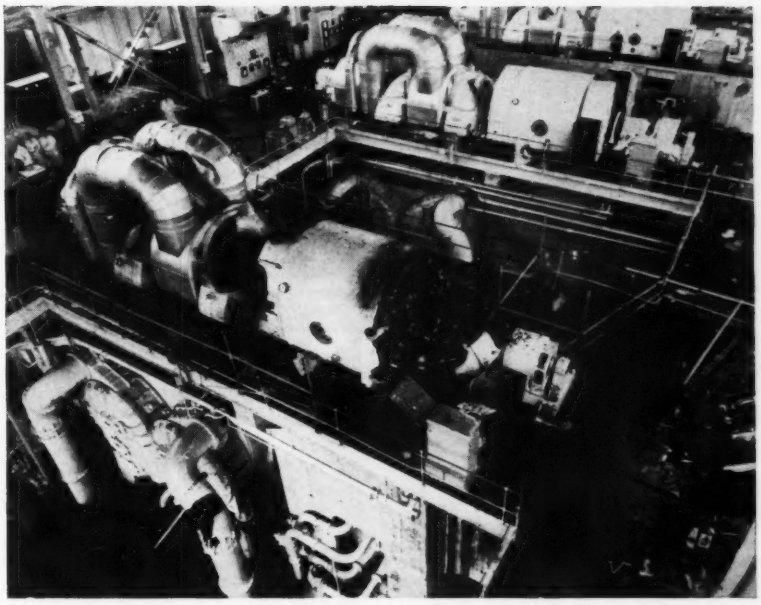
Other British exhibitors at Rome also reported a great deal of interest from Italian engineers. Clarke Chapman and Co. of Gateshead, for example, featured a full-size bank of boiler tube elements for Bradwell. I.C.I. showed two panels containing a typical selection of fuel cans and a selection of new metals developed for nuclear applications, including zirconium and titanium, etc.

On the instrumentation side, General Radiological featured a model of a flux monitoring cubicle as used in the control room of a nuclear power station. An actual rack, 6 ft 6 in. high, from the cubicle was also displayed. The rack contained the following equipment: ratemeter, logarithmic ratemeter, scaler, pre-scaler, shut-down amplifier, logarithmic d.c. amplifier and period meter.

Five valves typical of the wide range manufactured by Hopkinsons were exhibited on the company's stand. These valves included a patent 6-in. parallel slide unit, a torsion bar safety device, a Uniflow, Hopkinson/Ferranti main stop valve and a Hylif safety valve.

Agip Nucleare had two main exhibits. These were an electric analogue computer of their own design and manufacture for the simulation of reactor kinetics and samples of uranium ore which their associate company, SOMIREN, had prospected in Italy and Sardinia. The ores were displayed in separate compartments in a common case. Each sample had a geiger counter installed nearby and, at the press of a button, the counter indicated the activity: simultaneously, a light flashed on a relief map of Italy and Sardinia to indicate the location of the ore.

A general view of the Agip Nucleare—NPPC stand, with a 400 MW power station model in the foreground.



The scene in the turbine hall of Calder B following the disintegration of one of the turbines which overspeeded. Although the turbine was completely destroyed and adjoining equipment was badly damaged, none of the twenty or so personnel working in the hall was hurt.

World News

International

THE STAGE IS SET for the second Atoms for Peace Conference and Exhibitions (one governmental, one commercial) in Geneva from September 1 to 13. Forty-five governments and four international agencies have already submitted 2,370 abstracts of papers —more than double the total of 1,067 at the previous conference in 1955. Sixty-two governments will be represented at the conference. A special feature of the conference will be the reports from various countries on their fusion programmes: about 100 abstracts covering this aspect have already been submitted. So far as the commercial exhibition is concerned, 250 exhibitors from 13 countries will be taking space at the Palais des Expositions in Geneva for the period of the conference.

EURATOM is to undertake a fusion research programme costing $11 million in five years. This will be part of the $215 million appropriated for research under the Euratom treaty. The announcement was made by Professor Amaldi, chairman of the Euratom Scientific and Technical Committee after the committee's first meeting on July 7.

TEN-YEAR AGREEMENT between the Governments of U.K. and Japan for co-operation in the peaceful uses of nuclear energy was signed in London on June 16. The agreement allows Japan to purchase from the U.K. power and research reactors and the necessary fuel. It also covers the exchange of unclassified information and possible assistance in the construction in Japan of plants for making fuel elements and processing used fuel. Training facilities will also be made available in the U.K. for Japanese nationals.

The Japanese Ambassador in London, Mr. Katsumi Ohno, and Britain's Foreign Secretary, Mr. Selwyn Lloyd, signed an intergovernmental agreement for nuclear energy collaboration on June 16.

FIRST REPORT of the newly formed European Nuclear Energy Agency was released at an O.E.E.C. Press conference on June 19. Three main projects of the Agency are discussed: a factory for treatment of enriched materials at Mol, Belgium; the boiling water research reactor at Halden, Norway, which it is agreed will be operated as a joint venture, and the HAR, plans for which are to be finalized in September.

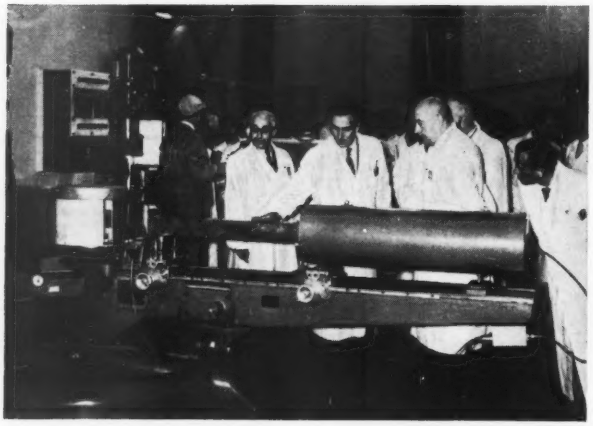
United Kingdom

HORACE, a zero energy reactor, is now operating at A.W.R.E., Aldermaston. Intended for the study of the nuclear characteristics of a light water research reactor, HORACE consists of an arrangement of enriched reactor fuel in ordinary water. It will be used to investigate reactor core arrangements and the use of different materials as reflectors.

Work with HORACE should speed commissioning of a second Weapons Group reactor of the same class. This second reactor at Aldermaston, named HERALD, is being built by A.E.I.-John Thompson, and should be completed by the autumn of this year. This will also have ordinary water as a moderator and coolant, will operate at power levels up to 5MW and will be used for research with neutrons and for the production of special isotopes.

"CO-OPERATION with Commonwealth countries in atomic energy matters is already so close and continuous that I do not think there would be any advantage in creating any formal organization," replied Mr. Macmillan to a question by Mr. Peart asking if he would initiate discussions with Commonwealth Governments on the need to create a Commonwealth Atomic Energy Organization. He added that there is to be an informal meeting of Commonwealth nuclear scientists in the U.K. in September and that in any case he would not wish to prejudice what might be discussed in Montreal when the Commonwealth Trade and Economic Conference meets in mid-September. Up to now it had been a tradition to deal informally and not to set up these formal bodies, but this approach might be modified.

THERMONUCLEAR research is being carried out at Queen's University, Belfast. Assisted by a grant of £4,500 from the A.E.A., the university is investigating plasma dynamics. Professor K. G. Emeleus, professor of physics at the university is honorary adviser to the N. Ireland Government on nuclear energy.



Following the inauguration of Poland's nuclear research station at Swierk, near Warsaw, the Prime Minister of Poland, Josef Cyrankiewicz (second from right), was shown over the centre.

DEVELOPMENT WORK on the production of thorium is now largely complete. The A.E.A. has sponsored small-scale production at a number of establishments and the plant set up by Thomas Firth and John Brown in Sheffield has now been closed down and the equipment will be stored. Although there are no immediate plans for thorium production at Springfields it would appear that the Authority, when the time comes, is intending to undertake such production itself instead of relying on industrial supplies.

HEAVIEST LIFT yet undertaken by the Goliath crane at Bradwell concerned the lower two courses of the spherical pressure vessel lifted as a single unit, 53 ft. in diameter and weighing 215 tons.

HUNTERSTON. Two men were seriously hurt after an explosion near the site whilst some waste material was being burnt.

AT. EN. DIVISION of the Geological Survey is currently engaged in an airborne radiometric survey of the West Country. Areas which justify closer examination will be investigated by ground parties equipped with portable scintillation and geiger counters.

RESEARCH at the Mechanical Engineering Research Laboratory at East Kilbride concerns the physical properties and basic processes of heat transfer and analysis of the performance of conventional and novel heat exchangers. Work is also in hand on the creep characteristics of irradiated uranium.

Austria

U.S. GRANT of $350,000 will be made on behalf of the nuclear research reactor project being undertaken by S.G.A.E., the Government - sponsored Austrian Study Company for Atomic Energy. The project calls for a 5-MW tank-type reactor, convertible to 12 MW. Light water cooled and moderated, heterogeneous, with solid fuel, it will be designed and built, near Vienna, by A.M.F. Atomics.

Canada

NUCLEAR POWER DIVISION of Atomic Energy of Canada was recently established to produce a preliminary design for a 200-MW nuclear station called CANDU (Canadian deuterium uranium reactor).

CONSTRUCTION of Canada's first nuclear power station at Rolphton, Ontario, has now been resumed. Work stopped last year because of radical design changes in the heavy water moderated, natural uranium reactor. The station, which will have a capacity of 20 MW (E) will serve as a pilot plant for 150-MW to 300-MW stations.

CONTRACT for engineering and construction of what is believed to be the world's first thorium recovery plant has been awarded by Rio Tinto-Dow to Humphreys and Glasgow (Canada). The plant will be built near Algom Quirke mine at Blind River, five miles north of Elliot Lake. Operation is scheduled for January, 1959, reaching full capacity by next May.

China

FIRST REACTOR is reported to have gone critical on June 16 according to New China News Agency. Built with the assistance of the U.S.S.R., the 10-MW heavy water research reactor is believed to be located near Peking at the Institute of Atomic Energy of the Chinese Academy of Sciences.

W. Germany

NUCLEAR BUDGET of approximately £16 million for 1958-9 represents a considerable increase over last year's expenditure. Programme covers experimental reactor construction and educationa! grants.

MUNICIPAL WORKS, Munich, in conjunction with AVR (Association for preparing experimental power reactors) plans to build first an experimental 15 MW(E) power reactor of the BBC/Krupp gas-cooled high-temperature type.

REACTOR THORIUM is being produced by Degussa in their new plant in Wolfgang nr. Hanau, from concentrates. This is sintered and converted into breeding elements for the research reactor FR-2, Karlsruhe.

HEAVY WATER pilot plant is to be built by Degussa and Uhde GmbH after process developed by Dr. E. W. Becker of Marburg. Process makes use of water-hydrogen exchange in presence of highly dispersed catalyst in a hot-cold system. Intended to integrate with existing hydrogen production plant so heavy water appears as by-product.

Hawaii

HAWAIIAN ELECTRIC CO. is considering construction of a nuclear power station and the Bechtel Corporation of San Francisco has been asked to recommend the most suitable type of plant. A site has already been selected.

Iceland

ICELAND has requested the co-operation of the European Nuclear Energy Agency in the construction and operation of a heavy water plant in Iceland, presumably using geothermal sources of energy.

Iran

RESEARCH REACTOR for installation at the University of Teheran's new science centre in Amirabad has been ordered from A.M.F. Atomics. It will be a 1-MW pool type using 20% enriched uranium alloyed with aluminium as a solid fuel

Italy

C.N.R.N.'s estimated budget for 1959 of 12.5 billion lire was approved at the June 11 meeting of the committee.

NUCLEAR-POWERED TANKER is being jointly considered by Fiat Motor of Turin and Ansaldo the shipbuilders of Genoa. According to Signor Ridolfo of Fiat the tanker envisaged will be of the Agrigentum type, displacing 68,800 tons. The PWR power unit rated at 74 MW(T) will develop 30,000 s.h.p.

FIRST PRIVATE RESEARCH REACTOR in Europe will be built by A.M.F. Atomics for Fiat and Montecatini. The unit will be a 1-MW pool type.

FURTHER DETAILS OF SENN TENDERS.—In response to their invitation for tenders for a 150 MW(E) nuclear power station, SENN (Società Elettronucleare Nazionale) received nine offers from America, France and Great Britain. The systems proposed, and the firms offering them, are as follow:—

Enriched uranium, boiling water, moderated: International General Electric, U.S.A., Mitchell Engineering, Great Britain, in association with Dr. W. H. Zinn and A.M.F. Atomics, U.S.A.

Enriched uranium, pressurized water moderated: Henry J. Kaiser Company, in association with Westinghouse Electric International, U.S.A., H. K. Ferguson Company in association with Babcock and Wilcox, U.S.A.

Enriched uranium, organic moderated: Atomics International, U.S.A.

Natural uranium graphite-moderated gas-cooled: Alsthom, France; A.E.I.-John Thompson Nuclear Energy Company, Great Britain; English Electric in association with Babcock and Wilcox and Taylor Woodrow, Great Britain; General Electric Company, Great Britain.

Japan

NEGOTIATIONS WITH CANADA have been started by the Japanese A.E.C. on uranium supplies. Local prospecting has yielded no worthwhile results.

Norway

U.S. GRANT of $350,000 has been made towards the cost of a zero-power, pool-type, facility fuelled with natural uranium and moderated and cooled with heavy or light water at the Institutt for Atomenergi, Kjeller, near Oslo.

New Zealand

COMMITTEE advising on the organization and administration of the proposed Institute of Nuclear Sciences was announced on July 9 by Mr. Holloway, Minister of Industries and Commerce. Dr. W. Harman is chairman; committee members include Sir Ernest Marsden, former head of the Scientific and Industrial Research Department, Dr. J. S. Watt of the Council of Scientific and Industrial Research and four others.

BULLER GORGE deposits now estimated to be capable of producing 750 tonnes per an. according to Dr. G. J. Williams. Opening-up operations have already started.

AUCKLAND ELECTRIC POWER BOARD proposes to hold an electrical exhibition in conjunction with B.E.A.M.A. at the Auckland Easter Show of 1959. This year the board celebrated the golden jubilee of the electricity supply industry in Auckland.

Pakistan

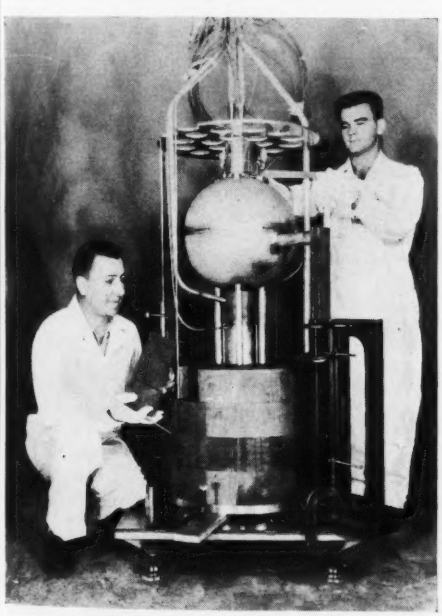
ADVICE on the establishment of an enriched uranium heavy water reactor is being given to the Government by an engineer from Argonne National Laboratory, U.S.A. At the request of the International Atomic Energy Agency Mr. Jordan T. Weills has recently visited Karachi for discussions with members of the Pakistan A.E.C.

Poland

FIRST RESEARCH REACTOR—a 2-MW swimming pool unit built with assistance from the U.S.S.R.—went critical early in June and was officially dedicated on June 14.

Sweden

AGREEMENT FOR CONSTRUCTION of R4/EVE—a natural uranium, heavy water moderated, 100-MW power reactor—has been reached by the Swedish Atomic Energy Company. The station, which will probably be located underground in south-west Sweden, is scheduled for completion in 1964. A.S.E.A. and Nydqvist and Holm share most of the main contracts. (*N.E.*, July, 1957.)



Core of the 50-kW research reactor which Atomics International is installing at Milan, Italy. The core, shown here inverted for ease of assembly, will contain uranium in a water solution.

NUCLEAR TANKER PROJECT for a vessel of 65,000 tons displacement with machinery developing 32,000 s.h.p. has been prepared by the Götaverken shipyard in Gothenburg. Preliminary plans call for a boiling water reactor with slightly enriched uranium fuel. Provision will also be made for Diesel generators as auxiliary power for manœuvring in harbours and channels because the designers feel that many authorities will not allow the reactor to operate in such circumstances.

United States

POWER SURGE in KEWB, water boiler type resulted in peak power of 530 MW less than 1 sec from initiation in special test. Reactor automatically shut off without damage.

(HT)GCRE TEST facility contract valued at $1.4 M awarded to Aerojet-General Nucleonics. Experimental reactor facility being built for Army at N.R.T.S. due for completion in May 1959.

IRRADIATION SOURCE for industrial use, comprising the primary circuit of the Hallam, Nebraska, 75 MW(E) sodium graphite reactor to be investigated by At. Int. for A.E.C. Ground broken for reactor, June 28.

SAFETY FUSE developed by Atomics International for pool reactors tested successfully in SPERT. Power surge, causes membrane to burst and BF_3 to enter core volume. Cartridge totally enclosed so no permanent poisoning results.

PULSED EXPONENTIAL experiment completed at the Rensselaer Institute. Water assembly containing 2½ tons uranium in 215 tubes, activated from below by Van der Graaf accelerating 3.10^{14} D/sec against Be target.

GROUND-BREAKING CEREMONY for Argonne National Laboratory Fuels Technology Centre took place at Lemont, Illinois on June 26. The centre will enable Argonne to accelerate and expand methods of using plutonium as a nuclear power reactor fuel. A.E.C. has allocated an initial $10 million for the centre.

A.E.C. LICENCES. To the University of Delaware at Newark for operation of a low power research reactor, a 100 MW AGN-201. To General Dynamics for construction of TRIGA—a 10 kW(T) heterogeneous tank type reactor, light water cooled and moderated with zirconium-hydride and water. Fuelled with homogeneous mixture of hydrided uranium-zirconium alloy containing uranium enriched to 20%.

MGCR—Maritime Gas Cooled Reactor—is to be developed by General Atomic division of General Dynamics Corporation under a contract with U.S.A.E.C. and the Maritime Administration. Contract is on cost plus fixed fee basis and the initial phase includes work on high temperature fuel elements, reactor controls, compatible power generation machinery and selection of coolant and moderator. The entire programme will take 5 to 7 years: preliminary investigations show that a gas-cooled propulsion unit will weigh less than other nuclear power plants for ships.

STUDY of industrial applications of high-level radiation will be made by Emerson Radio and Phonograph Corporation, a member of the C.E.M. (chemicals, electronics, metallurgy) group. Contract let by A.E.C. is for $86,847.

NUCLEAR PRODUCTS—Erco Division of A.C.F. Industries Inc., has obtained finalization of a contract from the A.E.C. for the development and construction of a demonstration nuclear power plant at Elk River, Minnesota. The agreement refers to a closed cycle boiling water reactor and conventional fuel-fired superheater with a combined capacity of 22 MW. The reactor will use water as a moderator and coolant and a mixture of uranium oxide and thorium as fuel. Estimated cost to the Commission will be $11.45 million. The site for the plant and the conventional turbo-generator will be provided by the Rural Co-operative Power Association at Elk River, Minnesota.

PROPOSALS for operating ALPR—Argonne Low Power Reactor—at the National Reactor Testing Station in Idaho have been invited by the A.E.C. ALPR—a prototype of a nuclear power plant for remote military installations—comprises a heterogeneous boiling water reactor with an output of 200 kW(E) and 1.3 million BTU/h for space heating.

PROCESS HEAT REACTOR has been proposed by Michigan Chemical Corporation. As outlined to the U.S.A.E.C. the plant, to cost $2.5 million, would initially produce steam at 81 cents per 1,000 lb with reduction to 70 cents later as fuel costs drop. Present cost of steam from fuel oil is 92 cents per 1,000 lb.

MARITIME ADMINISTRATION'S request for funds to initiate the conversion of a 22,500-ton oil tanker to nuclear propulsion has been rejected by the budget bureau. Conversion was estimated to cost $9 M, including $7 M for the reactor section. Both the Administration and the A.E.C. are anxious to promote the establishment of a privately owned nuclear-powered merchant fleet, but, apart from the discouragement of feasibility studies, conflicting responsibilities for development and operation have not been ironed out.

U.S.A.E.C. has established an historical advisory committee to discuss plans for the preparation of an official history of the Commission. Chairman of the committee is Dr. James Baxter, 3rd president of Williams College, Williamstown, Mass.

PHILLIPS PETROLEUM CO. have opened a uranium ore processing mill at McKinley County, New Mexico. The mill will process 1,725 tons of ore a day. Uranium concentrate will be sold to U.S.A.E.C. under a contract running until 1966.

U.S.A.E.C. has decentralized its access permit programme by allowing field offices to issue permits. It has also removed prohibitions on non-nuclear uses of uranium and made available for sale on an unclassified basis stocks of depleted uranium. The Commission's Chicago operations office will, in future, handle the commercial distribution of Boron enriched up to 92% in the isotope B.10.

U.S.S.R.

NUCLEAR RESEARCH CENTRE now being built near Tashkent, capital of Uzbekistan will be one of the largest of its kind in the U.S.S.R.

DISCUSSIONS on peaceful uses of atomic energy, attended by nuclear physics students from many countries open in Moscow on August 1.

Orbits in Industry

THE Press conference on the final Windscale report was, in its way, as disappointing as the first. That one produced no Sensational Disclosures; this, no real news of what was to happen. No one seemed to know whether either or both reactors would be scrapped, although Mr. Davey made a very good point when he drew attention to the fact that the two reactors do not constitute—by a very large jugful—the entire resources of Windscale, and that this establishment is hardly likely to come under the hammer even if the reactors cease to function.

Tangent's own personal reactions to the whole show could be summed up in the old Eastern proverb which, if his memory serves him right (and it seldom does), goes: "Man holding tiger by tail dare not let go." Which may, at first, seem a bit cryptic. As pointed out in these notes for November, 1957, the Authority, at the time of the Windscale incident, were faced with a truly frightful decision; whether to sit tight and say nothing, in the honest belief that no real harm had been done, or to set in motion the entire machinery for coping with a major disaster, and risk a lot of unwarranted sensationalism—still in the honest belief that no harm had been done. They chose the latter course, and it must have taken moral courage of a high order. They grasped, in fact, the tiger by the tail. Now, there is a certain difficulty about persuading the brute to go home again. The only way, it would appear, is to create an impressive array of sub-committees and working parties. Although none of them can kill it, if it is handed on from one to the other long enough, it will eventually get tired out and go to sleep . . . . Or is this an over-simplification of the matter?

Unfair to Filters

There were, incidentally, a couple of points not made clear at the conference. One was the importance of the Windscale piles for isotope production; the other referred to the filters. The rather vague reference to the "improvement" of the filters sounds as if they were being blamed for letting the stuff through, which is a bit rough on the manufacturers, who can hardly be expected to trap gaseous material, any more than anyone could be expected to make a waterproof colander. What was really meant was that the chimney could have what, one imagines, constitutes a miniature gas-washing plant, for chemical adsorption of the gaseous iodine.

Crying "Wolf!"

In the days when (here we go again!) safety regulations were not so rigid as they are nowadays, it was customary for most manufacturers to evolve their own. For high-voltage testing of units too large to move into a test enclosure, one used to surround them with a temporary fence of wide red tape strung from portable stands carrying appropriate danger notices, and apply the test from a portable (?) apparatus, familiarly known as the Coffee Stall. Management, which was pretty enlightened, even in those days, insisted that this was insufficient. All the notices had to be fitted with let-down flaps and the skull and cross-bones covered up until the actual moment of flashing, so that familiarity did not breed contempt.

Should not the same philosophy apply to the portable X-ray units that are coming into such general use in fabrication shops and on sites all over the country? Most of us must have, at some time or other, seen danger notices prominently displayed when it was obvious to anyone that the operators were changing films, and the only lethal object exposed anywhere was a cup of canteen tea. X-rays are less spectacular, and more difficult to detect than a flash test, since there is no corona hiss, and no smell of ozone (this saved Tangent from 27 kV one night when nobody had bothered to put up any tape at all). While a danger notice that doesn't mean what it says may keep the gaffer out of the way while the boys get down to a solo school behind a welding jig, it will eventually prove more dangerous than none at all.

Escalators for Ingots

Once upon a time, ingot casting was a matter of digging little canals in sand, running in the metal, and separating the lumps, when cold, by belting them with a 'eavy 'ammer. Tangent knew, of course, that this method had given way to metal moulds on roundabouts or escalators, but he didn't realize, until the recent visit to the new shops of Sheppards of Bridgend, that metal is far more touchy than human beings about riding conditions; and that if zinc, for example, didn't arrive under the cooling sprays with a face as unruffled as a family butler's the customers wouldn't buy, and that one had to go to extraordinary lengths to guard against even the variation in velocity of a chain passing over sprockets.

Gazing at this example of comfortable travel for zinc, one couldn't help wondering if, one of these days, uranium production will reach the stage where continuous casting of this sort is required, and the escalator will be atmosphere-conditioned as well as velvet-smooth. Let us hope, however, it won't be applied to plute. That doesn't like crowding, either.

What Price Research?

The Mullard film "Conquest of the Atom" (noted elsewhere) which was, incidentally, extraordinarily interesting, contained one short sequence on which a book could be written, when it compared the sort of apparatus a research worker requires today with the cork-and-sealing-wax lash-ups of the earlier workers, reminding us that research today is a costly business. Before the war, when the magic word "Research" did not always unlock a flow of gold from a beaming board, Tangent remembers hearing the research manager of a large organization gloomily pointing out that electricity might never have been discovered if Faraday had been subject to managerial control. One could imagine his Board's reply to his modest request for an iron ring and ten yards of wire . . . . "Good heavens! Mr. Faraday!! d'you think we're *made* of money?"

On the other side of the picture, of course, there is the story (vouched for) of another large research organization where a girl required a 3 ft length of $\frac{3}{16}$ in. platinum for some work. It was duly requisitioned but, in its progress through the system, somebody dropped out the denominator of the diameter. Eventually the lady was notified that her requirements had been fulfilled, and on calling at the stores, she was presented with a yard of 3-in. bar—well over a hundredweight of a metal that is, to put it mildly, far from inexpensive. Yet nobody had queried it.

DR. FINAGLE'S LAWS—2

First Law of Revision

Information necessitating a change of design will be conveyed to the designer after—and *only* after—the plans are complete. (Often referred to as the "NOW they tell us!")

Corollary I: In simple cases, presenting one obvious right way versus one obvious wrong way, it is often wiser to choose the wrong way so as to expedite subsequent revision.

"b"

The housewarming given by the Lead Development Association in their new Adam Street premises was responsible for a dereliction of duty on Tangent's part. When one considers the important part played by lead in the nuclear field, he really ought not to have allowed the householder in him to come uppermost, and spent all the time in fascinating conversations about flashings and gutterings. But even Jupiter nods, and nuclear work can be pretty dreary at times can't it? Be honest, now!

Tangent

Personal

Mr. Lewis L. Strauss (right) seen here with President Eisenhower will not be appointed for a further term of office as chairman of the U.S.A.E.C. His successor has not yet been nominated.

Appointments

Dr. Nyman Levin, chief of research and development, Rank Precision Industries, becomes deputy director of A.W.R.E., Aldermaston.

Mr. J. Walker, leader control and instrumentation group in the Reactor Engineering Division at A.E.R.E., Harwell, has been appointed to a senior post in the engineering division of Sperry Gyroscope.

Dr. Nyman Levin.

Mr. J. Walker.

Mr. L. Drucquer as general manager, **Mr. L. D. Anscombe** as chief engineer, **Mr. C. W. Furniss** as manufacturing manager, **Mr. R. M. Grant** as commercial manager and **Mr. N. R. D. Gurney** as executive (Manchester) of the newly formed A.E.I. Heavy Plant Division.

Mr. R. J. Cochran as general manager and commercial manager, **Dr. W. H. Darlington** as chief mechanical engineer, **Mr. W. H. Kilner** as chief electrical engineer, **Mr. R. R. Whyte** as manufacturing manager (Trafford Park), **Mr. D. R. S. Turner,** as manufacturing manager (Larne), **Mr. J. G. Body** as executive (Rugby) for the newly formed A.E.I. Turbine-Generator Division. **Mr. I. A. Ferguson** as manager large electrical machine sales, **Mr. P. S. Clayton** as manager power rectifier sales and **Mr. J. B. Siddaway** as manager compressor sales in the same division.

Mr. H. G. Bell who recently retired as chief engineer N.W. Electricity Board has been appointed consulting engineer, instrument and meter dept., Metropolitan Vickers Electrical Co.

Dr. Chauncey Starr, vice-president of North American Aviation and general manager of Atomics International, as president of the American Nuclear Society.

Mr. W. T. Bamford as chief generation engineer (operation) London division, C.E.G.B., **Mr. J. Harvey** as chief generation engineer (operation) South Eastern division and **Mr. W. H. Foster** as chief generation engineer (operation) Yorkshire division.

Mr. A. H. Tandy, lately Minister at the British Embassy in Buenos Aires, will succeed **Sir William Meiklereid** as head of the U.K. delegation to Euratom. Sir William is retiring from the Foreign Service.

Prof. Dr. Ing. S. Balke, German member of the Council of Ministers of Euratom, became president of the Euratom Council for six months from July 1. His predecessor was **R. Motz** (Belgium).

Mr. R. P. H. Yapp assumes the duties of director of finance of Vickers and Vickers-Armstrongs. **Mr. E. J. Waddington** will remain on sick leave until December 31, 1958, when he reaches the normal retiring age. **Mr. B. L. Snow** as sales manager of Vickers Armstrongs (Engineers).

Mr. Alfred L. Foulger as chairman and managing director of Hackbridge Holdings. **Sir W. Wavell Wakefield,** M.P., has resigned from the board but will continue in a non-executive capacity as consultant and adviser. **Mr. William L. Brown** has also resigned but will continue in a non-executive capacity with special duties.

Below we reproduce a photograph of **Mr. John McCone** who, as we announced last month, has been appointed fifth member of the U.S.A.E.C.

Mr. Andrew M. Brown as executive director with special responsibilities as personnel co-ordinator for The Plessey Co.

Mr. J. W. Ruddick as general manager of the Darlington Insulation Co.

Mr. H. H. Gorman as manager of U.S.A.E.C.'s newly established Lockland (Ohio) Aircraft Reactors Operations office. **Mr. John L. Wilson** as deputy manager.

Mr. F. Gordon Kay as a director of Acheson Colloids. **Mr. G. F. Henderson** as assistant sales manager Acheson Colloids. **Mr. T. Wint** as N.E. England sales engineer. **Mr. A. Cheney** as sales manager. **Mr. G. J. B. Davies** as general manager of Acheson Dispersed Pigments Co. **Mr. E. A. Smith** as assistant manager European Operations.

Dr. Robert C. Allen formerly with Los Almos (N.M.) Scientific Laboratory has joined the research department of Atomics International as group leader of experimental physics.

Mr. J. L. Ritchie as personal assistant to the managing director of Consolidated Pneumatic Tool Co.

Mr. Peter H. Jackson, M.C., as home sales manager of the Lancashire Dynamo Group.

Mr. T. J. R. Smith as sales manager of Hellerman.

Mr. Raymond Barrington Brock of Townson and Mercer as president of the Scientific Instrument Manufacturers' Association.

Mr. John McCone.

Dr. Chauncey Starr.

Mr. P. H. Jackson.

Mr. A. M. Brown.

The retiring S.I.M.A. president Mr. P. Goudime invests the new president, Mr. R. Barrington Brock.

Resignations

Brigadier-General K. E. Fields, general manager, U.S.A.E.C., resigned on July 1. He will be succeeded by **Major-General Alvin R. Luedecke,** U.S.A.F. Gen. Luedecke, at present Commander Joint Task Force 7, will assume his new responsibilities after conclusion of the present series of weapon tests in the Pacific. **Mr. Paul F. Foster,** assistant general manager, becomes acting general manager until Gen. Luedecke takes over.

Mr. R. W. Cook, deputy general manager, U.S.A.E.C., has submitted his resignation with effect from the adjournment of the current session of Congress. Mr. Cook will take up a post with the executive office of American Machine and Foundry.

Mr. W. Kenneth Davis, director of the division of reactor development U.S.A.E.C., resigned on July 31. He has accepted a position as vice-president of the Bechtel Corporation of San Francisco.

Sir Frank Spriggs has, by mutual agreement, relinquished his appointment as managing director of the Hawker Siddeley Group and has been succeeded by **Sir Roy Dobson.**

Mr. P. H. N. Ulander has resigned as executive technical director of James Howden and Co., but remains on the board.

Tours

Prince Bernhard of the Netherlands visited various A.E.A. establishments during the period July 16 to 18. A guest of Sir Edwin Plowden, chairman of the Authority, Prince Bernhard was shown developments at Harwell, Calder Hall and Dounreay.

Mr. P. B. Ades, sales manager, Airmec undertook a sales tour of Italy during June. At the end of the month a party of Dutch scientists visited Airmec's works.

Mr. V. A. Kennett, joint managing director of Plannair, recently visited the U.S.S.R. to discuss applications of the company's axial flow and centrifugal blowers and compressors.

Awards

Dr. Mark M. Mills, nuclear physicist, has been posthumously awarded the U.S. Presidential Medal of Freedom for "exceptionally meritorious service in contributing to the security of the U.S.A. and the welfare of the human race." Dr. Mills, deputy director of the University of California radiation laboratory, was killed in a helicopter accident on April 7 this year.

C.E.G.B. Project Group Appointments

Central Electricity Generating Board announce the following appointments to the three engineering project offices which the Board decided to establish to undertake construction work of power stations, including nuclear, and associated substations:—

Southern Project Group

Assistant chief project engineers: W. B. Shannon (former chief generation engineer (construction), London division); W. H. C. Pilling (former nuclear project engineer, headquarters).

Project engineers: J. Irlam (former chief generation engineer (construction), South Western division); J. Y. Hutchinson (former generation engineer (construction), London division); J. H. Osborn (former generation engineer (construction), London division); W. H. Sanderson (former project engineer, nuclear power branch, headquarters); E. T. K. Greenham (former mechanical engineer (construction), London division); H. B. Campbell (former generation engineer (construction), Eastern division); D. A. Pask (former project engineer, nuclear power branch, headquarters); H. Gleave (former generation engineer (construction), London division).

Programmes and progress engineer: P. M. Blake (former personal technical assistant to chief engineer, headquarters).

Administrative officer: J. C. Ivison (former senior assistant accountant, Eastern division).

Northern Project Group

Assistant chief project engineers: C. R. Watson Smyth (former chief generation engineer (construction), North West, Merseyside and North Wales region); B. C. Pyle (former chief generation engineer (construction), Southern division).

Project engineers: H. G. B. Mahon (former chief generation engineer (construction), North Eastern division); A. J. Hodgkinson (former generation engineer (construction), Yorkshire division); A. N. Duffett (former generation engineer (construction), North West, Merseyside and North Wales region); K. B. Harrison (former generation engineer (construction), North West, Merseyside and North Wales region); J. Shepherd (former generation engineer (construction), North West, Merseyside and North Wales region); C. E. Pugh (former generation engineer (construction), North West, Merseyside and North Wales region).

Programmes and progress engineer: T. J. Wilkinson (senior assistant engineer (construction), Southern division).

Administrative officer: N. Wells (former senior assistant accountant, North West, Merseyside and North Wales region).

Midlands Project Group

Assistant chief project engineers: F. Barrell (former generation station construction engineer, headquarters); L. C. L. Dale (former generation engineer (construction), Midlands division).

Project engineers: E. C. Shackleton (former generation engineer (construction), South Wales division); A. E. Farmer (former generation engineer (construction), Midlands division); F. Favell (former chief generation engineer (construction), East Midlands division); R. G. Millard (former generation engineer (construction), East Midlands division); A. H. Jones (former generation engineer (construction), East Midlands division).

Programmes and progress engineer: D. C. Bentley (former senior assistant engineer generation (construction), South Wales division).

Administrative officer: H. J. Bick (former deputy secretary, Midlands division).

Industrial Notes

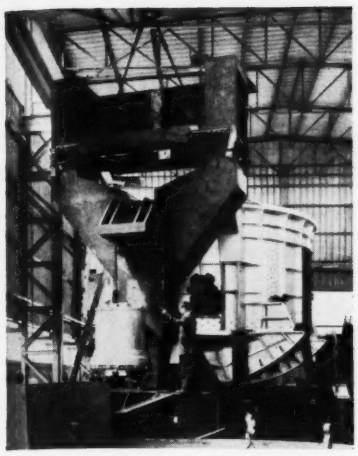
Babcock and Wilcox, of Great Britain and **Babcock and Wilcox** of the U.S.A. have decided to extend their existing technical collaboration into nuclear power construction. Both companies have for many years collaborated in the design of conventional steam-raising plant. There is no financial connection between the two concerns.

First of a series of seven talks on "The ABC of Atomic Energy," by Sir Christopher Hinton, was broadcast in the BBC programme London Calling Europe on July 20. The talks are to be transmitted in a wide range of European and Eastern languages. The BBC. has also published a booklet based on the series.

The John Thompson Group has inaugurated special welding courses at the company's new welding school at Wolverhampton. In addition to basic courses for trainees, an improvers' course is also being held.

Cape Asbestos have been awarded a contract for the thermal insulation of the 275 MW Berkeley nuclear power station. Cape Asbestos will carry out the entire insulation work, involving the two 80 ft high reactor vessels, 16 heat exchangers, CO_2 ducting and main steam pipes, in their own materials, Caposite moulded amosite asbestos insulation and Rocksil rock wool insulation.

Turrif Construction Corporation have received a contract for over £250,000 of civil engineering work at U.K.A.E.A.'s technical radiation centre at Wantage. There will be an extension of existing laboratory facilities together with buildings for the isotope division, including an isotope school.



Lifting a fabrication into place in the new heavy assembly shop of Sheppards of Bridgend.

British Overseas Fairs are organizing the next British trade fair, which is to be held from May 29 to June 14, 1959, at Lisbon.

Gresham Transformers have opened a new heavy transformer assembly bay at their Hanworth works. Units of up to 10 MVA can now be manufactured.

Vitro Engineering Co. has been awarded a contract for a feasibility study of an ultra high level radiation laboratory. The contract was awarded by Associated Universities Inc., the organization which operates Brookhaven National Laboratory.

Aerojet-General Nucleonics is planning construction of a 24,000 sq. ft engineering office and 18,000 sq. ft laboratory to be added to facilities at San Ramon, California. The company mass produces low power research and training reactors.

Rolls-Royce have set up a subsidiary company in Brazil to manage an aircraft engine overhaul and spares depot in the Sao Paulo area.

Babcock and Wilcox have opened a large new educational and training centre at the company's main works in Renfrew, Scotland. There are now about 760 apprentices in various stages of training at Renfrew.

Firth Cleveland Instruments have concluded a licensing agreement with the Gilbert and Barker Manufacturing Co. of Massachusetts to manufacture the Gilbarco electronic tank contents gauge.

Film Cooling Towers (1925) have been awarded a £750,000 contract by C.E.G.B. for four natural draught cooling towers at Rugeley generating station. The work will be carried out in collaboration with J. L. Kier and Co.

Two 90-ton elevated silos at West Kilbride station are helping to speed deliveries of bulk cement from the Clydebank works of Clyde Portland Cement Co. to the Hunterston nuclear power station site. Cement is delivered to the silos by British Railways 20-ton tanker wagons and then by bulk tanker road vehicles to the site. The silos have facilities for automatic weigh-batching.

A.M.F. Atomics have been awarded an A.E.C. contract for design and construction of a 1 MW forced circulation pool-type reactor for the Puerto Rican research centre.

Sheppard and Sons, Ltd., Bridgend, Glamorgan, have officially opened their works extensions. The new fabricating and erection shop, 170 ft by 70 ft, with 30-ft clearance from the hook of a 50-ton crane, offers unusual facilities for this part of the country, and has enabled some very heavy jobs to be tackled, including the fabrication of two 40-ton electric furnaces for Canada.

Sheppards of Bridgend, as the company is familiarly known, are within measurable distance of achieving their century of manufacturing in South Wales; the new shop is the commencement of modernization and expansion in the field of heavy plant for chemical and nuclear engineering.

F. W. Brackett and Co. have recently received a number of orders for their automatic travelling band screens for screening condenser cooling water at nuclear power stations. These orders include six screens for Berkeley (capacity 3.5 million g.p.h.), eight screens for Hinkley Point (4.3 million g.p.h.) and eight screens for Hunterston (3.24 million g.p.h.).

Société des Condenseurs Delas point out that the surface area of each of the heat exchangers which they supplied to Marcoule is 58,000 sq. metres and not 5,800 sq. metres as published in the data accompanying the drawing of G.1 in the June issue of *Nuclear Engineering*.

Sunvic Controls have received a further order from U.K.A.E.A. for six data handling equipments. The company recently completed two of these units for Capenhurst.

William Beardmore and Co. have just opened a new mechanical testing department at the company's Parkhead steel works, Glasgow, E.1.

Associated Electrical Industries announce that two product divisions became operative on July 1. They are the A.E.I. Turbine-generator division managed by Met Vick from the Trafford Park works in Manchester and the A.E.I. Heavy Plant division managed by B.T.-H. at Rugby.

General Atomic, division of General Dynamic Corporation, has been awarded a feasibility study by the U.S. Air Research and Development Command for the possible development of a new concept of propulsion employing controlled nuclear detonations. Initially $1 million will be spent on research into the project.

James Hodgkinson (Salford) have acquired **J. and J. Neil (Temple)** of Temple Park Iron Works, Glasgow, W.3. The company has been appointed sole representatives in Scotland for three member companies of the Hodgkinson group, **Bennis Combustion, Bennis Mechanizations** and **Saxon Engineering.** The London office of the group is now Brettenham House, Lancaster Place, Strand, W.C.2. Telephone: Covent Garden 2188-9.

Sylvania-Corning Nuclear Corp. awarded by PRDC contract valued at over $1 M for manufacture of core and blanket elements for initial loading of the 100-MW Enrico Fermi fast breeder reactor (*Nuclear Engineeering*, March, 1957). 100 core and 300 blanket sub-assemblies are involved. Production will begin immediately in the expanded facilities at Hicksville, L.I., and delivery is scheduled for completion in late 1960. Silcor supplied elements for reloading of Brookhaven reactor at low price of $50 each; full loading comprises 4,000 elements.

Atomics International are to build a $2 million remote handling facility for studying radioactive materials at the company's nuclear field laboratory near Los Angeles.

Address Changes

Borax Consolidated. Midland branch sales office now at Griffin House, 18/19 Ludgate Hill, Birmingham, 3.

Evode are moving their London office to 82 Victoria Street, London, S.W.1.

Lead Development Association have moved to 18 Adam Street, Strand, London, W.C.2.

Mucon Engineering have moved to new premises at Stonefield Way, South Ruislip, Middlesex. Telephone: Byron 7261/7262.

Pelapone Engines. Sales division now located at 38/40 Bruton Street, London, W.1. Telephone: Mayfair 2034.

Ransome and Marles ask us to say their Glasgow office is now at 380 Argyle Street. Telephone: Central 3948.

Film

Conquest of the Atom.—Second in the "History of Modern Science" series, this film was sponsored by Mullard Ltd., in association with the National Committee for Visual Aids in Education. The story commences with the opening of Calder Hall and then goes back to J. J. Thomson's work on discharge tubes in 1897, and his discovery of the electron. The history of atomic research is then traced through Rutherford, Cockcroft and Walton and others, and gives a simple explanation of nuclear fission, with the aid of animated diagrams, and the application to energy supply. In the final section a comparison between the simple home-made apparatus of the early workers and modern research apparatus, including Zeta. Produced by the Realist Film Unit, in Eastmancolour, the film is directed by Alex Strasser, and has a commentary by Derek Guyler. Running time 22 min. Distributed by E.F.V.A., 33 Queen Anne Street, London, W.1.

Sir John Cockcroft with a model of his old laboratory and Alex Strasser during the making of the Mullard film "Conquest of the Atom."

Processes and Equipment

For further information on any item please enter the relevant number on the Reader Service Card enclosed with this issue and forward the card to the address given.

TV Assisted Manipulator

A new remote control manipulator with a television eye and designed for removing irradiated fuel elements from Windscale-type piles was recently manufactured by Sir W. G. Armstrong Whitworth Aircraft to A.E.A. design. The unit incorporates a Marconi TV channel. Pending a decision on the future of the No. 2 pile at Windscale, the unit will be used for maintenance work inside the pile.

The grab, television camera and light are mounted on a boom capable of rotary and lateral movement and carried on a sectional retractable column. The operation of these parts is controlled from a derrick head which houses the viewing monitor, television control unit, position indicating dials, self-winding cable drums and hoist.

In the Windscale pile, spent fuel elements are discharged into a space between the discharge face and the biological shield. From this space, known as the discharge void, the spent elements are removed for disposal. Some cartridges, however, lodge on the arms of a burst cartridge detection scanner, or on ledges on the pile face. Many of these can be removed or dislodged with long tools inserted through inspection holes. Because the whole of the discharge face is not visible through these holes it is possible for some cartridges to lodge in concealed positions. When this occurs it is important that they should be speedily detected and removed.

The new device can be used after each discharging operation to inspect the discharge void, and to remove any cartridges left inside the pile. The boom carrying the camera and grab is lowered through one of the access holes in the top of the pile and the face is systematically searched. The grab, which is situated in front of the camera, can be closed to grasp and remove any cartridges in focus. Maximum depth of operation is 60 ft. A feature of the equipment is the provision of automatic stops to prevent the camera being damaged or lost through collision with any obstruction within the area of its operation.

The television component is the new Marconi BD871 vidicon television channel designed for closed-circuit applications. The camera is cylindrical in construction and measures only 4 in. in diameter. It incorporates automatic sensitivity control, which compensates electronically for variations in scene illumination to present a picture of constant brightness on the monitor screen. A remote focusing attachment at the rear of the camera unit is operated from the main control position. Special provision has been made to seal the camera against the ingress of radioactive dust. The associated control unit measures 14 in. by 17 in. by 8 in. A Marconi 14-in. industrial monitor is used to give a 625-line display.

(Sir W. G. Armstrong Whitworth Aircraft, Ltd., Coventry.)

(Marconi's Wireless Telegraph Co., Ltd., Chelmsford, Essex.)

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Patchboard Computer

Although introduced only at the end of last year, Pace 231 R computers have already been sold to a large number of companies and organizations interested in the development of nuclear energy. Because of the modular grouping of components an operator can set up problems rapidly on the patchboard. A prepatch panel with 3,450 holes facilitates use of jack plugs and short patch cords. All possible high-impedance points are shielded.

The patchboard itself can terminate 100 operational amplifiers and associated non-linear equipment, and has complete automatic readout. It provides for individual operational control of all integrators. Included are 30 combination summing-integrating amplifiers, 45 summing amplifiers, 25 inverters, 200 trunks, 150 coefficient pots, 20 ten-segment DFGs, 10 electronic multipliers, 10 five-channel servomultipliers, five servo resolvers, 5 function-of-two-variables generators, 3 eight-channel recorders for X-Y plotters, 10 comparators, 20 function switches, 15 limiters, 20 passive elements and 225 jacks on the patch panel for miscellaneous expansion.

A high-speed digital voltmeter on the control panel indicates both the voltage reading and address of the component being measured. An automatic, digital input-output system permits complete control of the computer from previously prepared punched paper tape.

(Electronic Associates Ltd., Long Beach, New Jersey, U.S.A.)

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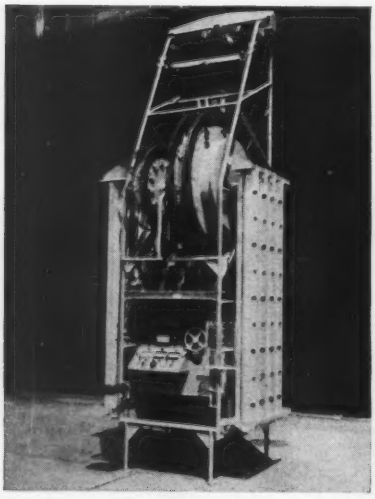
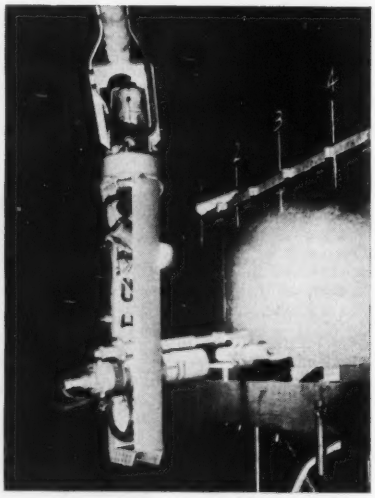
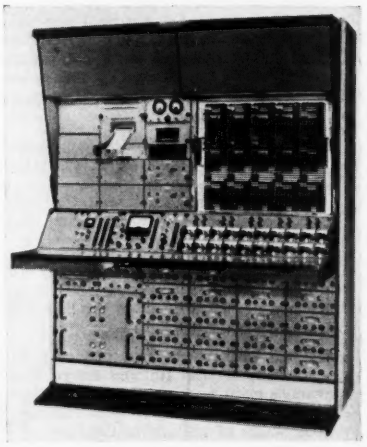


Derrick head of the Armstrong Whitworth manipulator: the Marconi monitor and control desk is located at the base of the unit.



The Marconi camera and grab unit in operation showing how fuel elements are picked up for removal from the discharge void.



Pace 231 R computer with patchboard.

New Particle Accelerator

A new Van de Graaff particle accelerator model PN-250 for pulsed neutron output in conjunction with sub-critical assemblies, reactor design studies and nuclear engineering training has been developed by High Voltage Engineering Corporation. The model PN-250 has an energy rating of 0.25 MeV, nominal, with ion current during pulse of 50 microamperes, nominal. Pulse length is 100 microseconds; this figure, however, is adjustable to pulse lengths in the 25-250 microsecond range at the option of the user. Pulse rise and decay time is less than 5 microseconds, with a pulse repetition rate of 400 pulses per second, nominal and synchronous with the alternator supplying ion-source power. Weight of the model PN-250 accelerator is 1,200 lb.

(High Voltage Engineering Corporation, Burlington, Massachusetts.)

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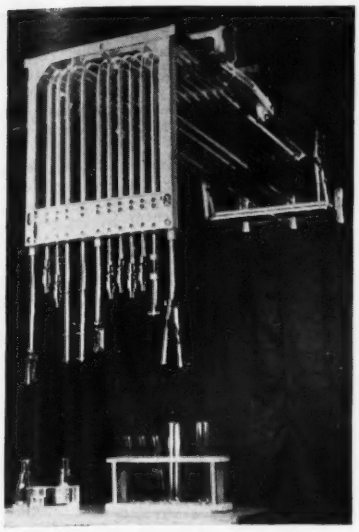

Remote manipulator for chemical analysis designed in collaboration with the U.K.A.E.A. by J. Evans and Son (Portsmouth). Installed at Dounreay. (1136)

Counter Display Unit

A transistorized universal counter with in-line read out, model SA.501, is now available from Racal Engineering. It can be used to measure frequencies of up to 50 kc/s, time intervals or for batch counting up to 9,999. Power read out facilitates use of the unit as a control device. The time base is variable from 1 millisecond to 10 seconds in 1 millisecond steps. The SA.501 can be mains or battery powered, the power consumption being 5 watts.

(Racal Engineering, Ltd., Western Road, Bracknell, Berks.)

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Racal Counter, model SA.501.

Examining steel plate for flaws with a Kelvin Hughes Autosonic Mk. 1.

Temperature Scanning Unit

A recent development of the Fielden potentiometric scanning system has resulted in the introduction of a compact unit arranged for automatic scanning of up to 50 temperature points. Temperature is indicated on a large dial approximately 2 ft. diameter: around the periphery of this dial are point numbers from 1 to 50. A motorized scanning switch enables the equipment to examine each point in turn and a clear Perspex pointer tipped black, indicates the number of the point under examination at any one time.

As it cannot be expected that the desired value for all points will be the same it is possible to have a different set point for each of the 50 variables. The value of the set point is shown by the position of a red pointer and this can be adjusted by a small potentiometer under the indicator bezel and in line with the temperature point number.

The actual value of the temperature is shown by the position of a green pointer and the measuring circuit is potentiometric. Thermocouples are used as the detecting elements and the output voltage of the thermocouple is compared with a stable d.c. voltage by means of a self-balancing servo mechanism.

On a large plant certain of the temperature variables may have to be held to closer tolerance than others and to cope with such a situation the equipment has three tolerance bands which can be adjusted to required values. Any number of temperature points can be allocated to any of these three bands. This will then enable the more important variables to give an alarm should they deviate by more than, say, 5%, others may be set to give an alarm should they deviate by more than, say, 10%.

In normal operation the equipment scans the 50 points in sequence, the red pointer balances to the desired value and the green pointer balances to the actual value. If the difference between these pointers is more than the pre-fixed amount for that particular point, then the scanning switch will stop and the signal lamp corresponding to the particular tolerance band will be illuminated. The scanning switch can be restarted either by bringing the temperature to within the pre-fixed tolerance band or by manually switching the scanner to the next point in the sequence.

Manual override is possible and this feature enables any temperature point to be indicated at will without waiting for the scanner to reach that point in its normal sequence. Push buttons are also provided which will stop and start the scanning switch so that this can be arrested on a particular point for any desired length of time. The speed of scanning is approximately six seconds per point and one point can be wired from the constant voltage source in order to check the operation of the equipment.

(Fielden Electronics Ltd., Wythenshawe, Manchester.)

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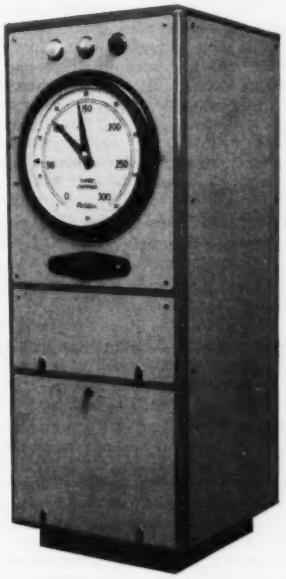

Automatic temperature scanning unit developed by Fielden Electronics.

Ultrasonic Flaw Detection

Steel plate used for fabricating pressure vessels at the works of Motherwell Bridge is now being examined for flaws with the aid of a Kelvin Hughes Autosonic Mk. 1. The equipment comprises two units in a device housing the necessary probes (known in the shop as the "mower") and a control console.

The "mower" embodies three sub-units: a probe assembly consisting of 14 barium titanate crystals, seven in parallel in the transmitter and seven in the receiver; a reservoir tank which supplies water to act as an acoustic couplant between the probes and the plate and a fault indication system comprising a crayon mounted on a movable slide and controlled by a relay.

The console comprises an oscilloscope and controls for range, sensitivity, fault gating system and a fault warning system.

In operation the probe unit is placed on a standard block containing faults of known size. The equipment is then set up on this block to record faults of the required size and above. The amount of testing required depends on the application of the plate. Some plates are examined 100% in both directions, others 100% in one direction and, in some instances, the examination is limited to the plate edges and down each centre line of the plate.

When the mower passes over a fault the warning systems on both the console and the mower operate. The relay in the mower is energized, moving the chalk out of alignment and keeping it there as long as the fault is detected, thereby giving a rough location of the fault. A relay on the console is also energized and lights an amber lamp on the top of the console, the fault also appears on the trace on the 'scope and a trained operator can gain an idea of the flaw size.

A further indication which can be employed is the use of a pen recorder which operates in conjunction with the other warning devices: thus a graphical record of fault position on the plate can be obtained.

(Motherwell Bridge and Engineering Co., Ltd., Motherwell, Scotland.)

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Patents Reviewed

These abstracts have been made from British Patent Specifications, complete copies of which can be obtained from the Patent Office, 25 Southampton Street, London, W.C.2, at 3s. 6d. each (including postage).

B.P. 789,257. Fuel elements for nuclear reactors. W. B. Hall, T. Davis. To: U.K. Atomic Energy Authority.

With higher heat ratings in thermal reactors having deep-finned elements to conduct a higher heat flux, there is an increase in the temperature difference between root and tip of the fin so that the tip serves little purpose from a heat transfer aspect. Without the tip, less pumping power is needed. This leads to a design of rod-like or tube-like fuel elements shaped so as to be undulating in longitudinal section and enclosed in a protective sheath (of stainless steel) of constant cross section.

B.P. 789,441. Process for the fluorination of organic compounds. To: U.K. Atomic Energy Authority.

The organic compounds are aliphatic hydrocarbons or their partial fluorination products. The compound is fed in the vapour state to a reaction zone in which finely divided cobalt trifluoride is maintained at fluorinating temperature in fluidized condition. Fluorination of the compound and conversion of the trifluoride to difluoride occur. The cobalt difluoride is separated and reacted with free fluorine in gaseous form to regenerate the trifluoride, with which then further quantities of the aliphatic hydrocarbon are reacted.

B.P. 789,456. Method of treating materials with high energy particles. J. B. Birks. To: British Dielectric Research, Ltd.

A first part of the particle beam impinges on one side of the body, a second part passes the body and enters a uniform magnetic field by which it is deflected back to impinge on the opposite side of the body. The magnetic field is arranged transversely to the direction of the beam and strong enough to cause the beam to be deflected through approximately 180 deg. in a curved (circular or spiral) path. A particular application is the irradiation of an electric cable moving through the beam where penetration of the body is obstructed by the conductor.

B.P. 789,663. Production of denser graphite. G. H. Greenhalgh. To: U.K. Atomic Energy Authority.

Refers particularly to the production of electrodes of artificial graphite where density is important because of reduced power consumption, breakage and rate of wear. The dense graphite is prepared by heating a mass of calcined carbonaceous material free from sulphur, nitrogen and oxygen to a graphitizing temperature of 2,200° to 2,700°C.

B.P. 789,482. Nuclear reactor arrangements. P. A. Lindley. To: General Electric Co., Ltd.

A gaseous cooling medium is usually circulated through the reactor core and the heat exchange system at relatively high pressure. If a centrifugal impeller is used it is surrounded by a diffusing casing, and the required shape, large in diameter but of short axial length is unsuited to withstand high internal pressures. The problem has been solved by arranging both impeller and diffusing casing within the existing pressure vessel surrounding a heat exchanger or the reactor core.

B.P. 789,894. Purification of thorium. R. Lind, T. A. Ingles. To: U.K. Atomic Energy Authority.

The impure thorium compound mixed with carbon and formed into pellets or briquettes is chlorinated in the lower part of a vertical (silica) column at 850° to 920°C. The part is closed by a (silica) grille which supports a fractionating packing (ceramic material or porous carbon) and a condensing surface. Thorium tetrachloride of enhanced purity is obtained.

B.P. 789,937. Nuclear reactor and process for converting nuclear energy into mechanical and/or heat energy. To: Stichting Reactor Centrum Nederland (Netherlands).

The reactor contains boiling active liquid (moderating liquid containing fissile material in solution and/or in a finely divided state) in the reaction zone. This liquid is wholly or largely dispersed in vapour of the moderating liquid. The vapour is continuously withdrawn from the reaction zone being rendered free from entrained liquid and/or solid and utilized for the required mechanical energy (turbine) and/or heat energy (heat exchanger) while further moderating liquid is supplied continuously to the reaction zone to replace that withdrawn as vapour. A reactor of this type may be as large as desired in a lateral direction, so that production of energy may be made as large as desired while the height may be no more than 1 to 2 m. The decisive factor is the maximum permissible vapour velocity for the drops of liquid to be able to fall.

B.P. 790,296. Preparation of di-potassium uranous fluoride. To: U.K. Atomic Energy Authority (U.S.A.).

By heating uranous oxide with potassium acid fluoride at about 800°C.

B.P. 790,306. Cleaning compositions for surfaces contaminated with heavy metal compounds. E. A. Saxon-Napier. To: Brentford Soap Co., Ltd.

Refers in particular to deposits of radioactive materials, such as fission products from an atomic pile, on laboratory and industrial equipment, clothing, human skin. Such deposits can be removed by an aqueous cleansing cream comprising an alkali metal (ammonium, substituted ammonium, alkylolamine) salt of a polyaminopolycarboxylic acid (nitrilitriacetic acid) complexing agent, or of an alkaline earth metal complex thereof, water and a water-soluble polymer known to give aqueous solutions of high viscosity. The composition is first put on the surfaces to be cleaned, which are then flushed with water until the cream has been removed.

B.P. 790,041. Extraction of plutonium from aqueous solution. A. G. Maddock, A. H. Booth (Canada).

Plutonium can be extracted from aqueous solutions containing oxalate (as obtained by the process described in B.P. 783,601, *Nuclear Engineering*, March, 1958) by treating the solution with cupferron so as to form a complex of plutonium and cupferron, which is extracted by a water-immiscible organic solvent. Plutonium may thus be obtained from the organic solvent phase by standard methods. A very convenient method is based on the photo-instability of cupferron; the solvent phase is subjected to light and the plutonium resulting from decomposition of cupferron complex washed out with dilute mineral acid.

B.P. 790,156. Radiation shielding containers. To: Farrel-Birmingham Co. Inc. (U.S.A.).

A sectional container for radioactive material whose sections may be used either singly or in multiple so as to vary size and weight as required. The container comprises a cylindrical bottom part and an upper part which may be either the cover, or one or more intermediate sections and a cover. Each intermediate section has a frustro-conical or stepped boss on top, and a similarly shaped recess around the cylindrical portion forming the chamber for the radioactive material. The parts are individually screwed together and harmful rays cannot pass outwards through the joints.

B.P. 790,319. Containers for radioactive materials. E. K. Cole, Ltd., R. G. Davis.

A shallow (pressed sheet metal) tray with a wide peripheral flange and a sheet-metal cover of similar external dimensions with an aperture locating a window of metallic foil hermetically sealed around the aperture for use as a thickness gauge. As a sealing medium, an epoxide casting resin is employed. A metal washer may be inserted and for storage and transport a second metal cover is clamped on top for absorbing radiation passing through the window. The radioactive material is sealed in silver foil to form a wafer-like package in the shallow tray.

B.P. 790,334. Canning of metals. A. B. McIntosh, K. Q. Bagley. To: U.K. Atomic Energy Authority.

Instead of using metals resistant to the action of uranium, plutonium and thorium for canning these fuels in nuclear reactors, a close fitting envelope is made of metal, not necessarily inert towards the contained metal at temperatures below 800°C, over a thin interlayer of niobium metal between envelope and fuel. The interlayer, 1-2 mils thickness, may be formed either on the fuel metal or on the envelope or on both by electrodeposition, evaporation, metal spraying, or other means, or the niobium may be wrapped around as a foil. After applying the layer and sealing the envelope the assembly is subjected to pressure for close contact.

B.P. 790,345. Separation of zirconium and hafnium compounds. R. B. Eaton. To: E. I. Du Pont de Nemours and Co.

Zirconium and hafnium halides are separated from vaporous mixtures by contacting the mixed halide vapours with a solvent consisting of or comprising molten alkali metal halide, followed by fractionation.